IISS Research Bulletin

Nitrate Contamination of Groundwater in Some Heavily Fertilized and Intensively Cultivated Districts of India

A.K. Biswas, Sanjay Srivastava, A. Subba Rao, G.V. Lakshmi,
B. Mandal, B. Singh, R.N. Katkar and Murugesa Boopathi

Indian Institute of Soil Science
Nabi Bagh, Berasia Road, Bhopal - 462 038 (M. P.)

IISS Research Bulletin No.1

Nitrate Contamination of Groundwater in Some Heavily Fertilized and Intensively Cultivated Districts of India

A.K. Biswas, Sanjay Srivastava, A. Subba Rao,
G.V. Lakshmi, B. Mandal, B. Singh,
R.N. Katkar and Murugesa Boopathi

भाकृअनुप
ICAR

Indian Institute of Soil Science
Nabibagh, Berasia Road
Bhopal-462038
M.P.

About Authors : **A.K. Biswas,** Pr. Scientist & Head, Div. of Soil Chemistry & Fertility
Sanjay Srivastava, Sr. Scientist, Div. of Soil Chemistry & Fertility
A. Subba Rao, Director, Indian Institute of Soil Science, Bhopal
G.V. Lakshmi, Professor, A.N.G.R.A.U., Bapatla, Andhra Pradesh
B. Mandal, Professor, B.C.K.V., Kalyani, West Bengal
B. Singh, Sr. Soil Chemist, P.A.U., Ludhiana, Punjab
R.N. Katkar, Assoc. Professor, P.D.K.V., Akola, Maharashtra
Murugesa Boopathi, Vice-Chancellor, T.N.A.U., Coimbatore, Tamil Nadu

Published by : **A. Subba Rao**
Director
Indian Institute of Soil Science, Bhopal-462 038
Tel: +91-755-2730946, Fax: +91-755-2733310
Email: director@iiss.ernet.in

Copy rights reserved : **Indian Council of Agricultural Research**
New Delhi - 110 001

Correct Citation : **Biswas, A.K., Srivastava, Sanjay, Subba Rao, A., Lakshmi, G.V., Mandal, B., Singh, B., Katkar, R.N. and Boopathi, Murugesa (2010). Nitrate Contamination of Groundwater in Some Heavily Fertilized and Intensively Cultivated Districts of India. IISS Research Bulletin No.1, Indian Institute of Soil Science (ICAR), Nabibagh, Bhopal, pp 1-89.**

Printed at : **Neo Printers, 17, Sector-B, Govindpura, Industrial Area, Bhopal**
Phone : 0755-4235558, 4236558
E-mail : neoprinters@gmail.com

Contents

Chapter		Page No.
Foreward		v
Preface		vii
Acknowledgement		ix
1.	Introduction	1
2.	Objectives	3
3.	Study Area	3
3.1	Background of the target districts	3
4.	Sampling Scheme	12
5.	Collection, Preservation and Analysis of Groundwater Samples	23
5.1	Well inspection	23
5.2	Order of sampling	23
5.3	Water-leval measurements	24
5.4	Sample collection from different sources	24
5.5	Sample containers, filling method, preservation and holding times	24
5.6	Analysis of nitrate in water and soil extract	25
6.	Results	25
6.1	Level and extent of nitrate contamination	25
6.2	Temporal variation in nitrate contamination in the representative aquifers	40
6.3	Distribution of NO_3-N in the soil profiles of the selected sites	55
6.4	Vulnerability of groundwater to nitrate contamination	62
6.5	Mapping and delineation of nitrate contaminated areas	82
7.	Summary and Conclusions	85
	References	88

Foreword

Nitrogen is a major constituent of the earth's atmosphere and occurs in many different gaseous forms such as elemental nitrogen, nitrous oxide and ammonia. Natural reactions of atmospheric forms of nitrogen with rainwater result in the formation of nitrate and ammonium ions. While nitrate is a common nitrogenous compound generated due to natural processes of the nitrogen cycle, anthropogenic sources have greatly increased the nitrate concentration in groundwater. The largest anthropogenic sources are septic tanks, cattle dung, urine and nitrogen fertilizers. Levels of nitrates in groundwater in some instances are above the safe levels proposed by the World Health Organization (WHO) and thus pose a threat to human health especially to infants in rural areas where incidence of methemoglobinemia appears to be the result of high nitrate levels. Methemoglobinemia, or blue baby syndrome, robs the blood cells of their ability to carry oxygen. High nitrate levels in aquifers also lead to eutrophication. Due to the detrimental ecological effects, treatment and prevention methods must be considered to protect groundwater aquifers from nitrate leaching and accumulation in high concentrations.

It is heartening to note that the research bulletin entitled "Nitrate Contamination of Groundwater in Some Heavily Fertilized and Intensively Cultivated Districts of India" has reported nitrate levels of different water bodies and possible causes of such nitrate concentrations. The workers have done commendable job in surveying six heavily fertilized districts of different states and reported the nitrate content. Nitrate contaminated areas of each district have been delineated and mapped, which will help the planners and policy makers in managing soil and water in those districts.

I am sure these findings will guide the different stakeholders in making best management practices in agriculture and also in the management of wells and sanitation activities. I congratulate all the scientists from IISS, Bhopal and coordinating institutions who contributed in this research and brought out this invaluable publication.

Date: December 23, 2010
Place: New Delhi

(A.K. Singh)
Deputy Director General (NRM),ICAR
New Delhi

Preface

The IISS is an organization under aegis of Indian Council of Agricultural Research (ICAR), with a mandate to provide scientific basis for enhancing and sustaining productivity of soil resources with minimal environmental degradation. Therefore, monitoring the soil and water environment is our focal area of research and this publication covers a very important constituent nitrate that is actually required in soils as a source of nitrogen but its access not only leads to contamination of water bodies resulting in eutrophication of lakes causing environmental degradation but is also harmful to human being if its concentration in water exceeds 10 mg nitrate N per litre. Hence IISS took up a project on nitrate contamination of water bodies in six heavily fertilized and intensively cultivated districts of India, namely, West Godavary in AP, Hooghly in WB, Hoshangabad in MP, Coimbatotre in TN, Ferozepur in Punjab and Jalgaon in Maharashtra. The project was undertaken in a networking mode with the participation of SAUs, namely, APAU, Bapatla; PAU, Ludhiana; BCKV, Kalyani; TNAU, Coimbatore and PDKV, Akola.

This report covers the nitrate concentration of different water bodies classified as per the types of wells, nearness to anthropogenic activities, depth of well, and fertilization rates. The report delineated the areas where nitrate concentration has increased beyond the safe limit and explored the possible reasons for such high levels. Out of the six districts surveyed, only the target district of Godavari represented the case where excessive use of fertilizers probably caused high nitrate levels of ground water and reached a flash point requiring immediate attention. However, in other districts, unconfined aquifers like dug wells, open wells, and hand pumps were much more polluted than deep and confined aquifers and organic sources of nutrients, human and animal excreta played a major role in nitrate contamination of ground water.

I congratulate the project team for their commendable efforts in generating useful information on nitrate contamination of groundwater. I hope the information and data documented in this bulletin will be of immense help to the administrators, policy makers, environmentalists, researchers, students and various other investigating agencies working in related issues.

(A. Subba Rao)
Director
Indian Institute of Soil Science

Date: December 23, 2010
Place: Bhopal

Acknowledgements

Nitrate is one of the major agriculture-derived pollutants leaching to groundwater. Nitrate leaching from agricultural production system is blamed for the rising concentrations of nitrate in ground and surface waters around the world. In India, there have been sporadic reports of elevated nitrate concentrations in groundwater in different parts of the country, and fertilizer has been made the culprit by various environmentalists and green groups without proper database backup on nitrate contamination of groundwater. With this premise, a project entitled "Delineation and mapping of nitrate contamination in water in heavily fertilized and intensively cultivated districts of the country" was awarded to IISS, Bhopal by Indian Council of Agricultural Research, New Delhi under AP Cess Fund Scheme. The project was undertaken in a net-work mode with IISS, Bhopal as the lead center and APAU, Bapatla, PAU, Ludhiana, PDKV, Akola, TNAU, Coimbatore and BCKV, Mohanpur as the cooperating centers. The contents of this bulletin have been extracted from the results of this project and while reporting it, it's my proud privilege to thank the Council for financial and technical assistance to carry out this work.

I express my sincere thanks and gratitude to Dr. J. S. Samra and Dr. A.K. Singh, DDG (NRM) and Dr. P.D. Sharma, ADG (soils) for their noble guidance, generous support and encouragement in awarding and executing this project. Special thanks are also due to the Vice-Chancellors and Directors of Research of PAU, Ludhiana, BCKV, Mohanpur, ANGRAU, Bapatla, TNAU, Coimbatore and PDKV, Akola for their constant support towards this programme.

I also extend my heartiest thanks to the Hon'ble Director, Dr. A Subba Rao for his continued patronage and encouragement for running the project, and Dr S Kundu, Head, Division of Environmental Soil Science for his unstinted support and desired counseling in the execution of the project work from time to time. The helps rendered by Drs. K.N. Singh, Principal Scientist and Abhishek Rathore, Scientist in planning the sampling strategy, statistical analysis and mapping the districts are also thankfully acknowledged.

I would like to place on record my sincerest thanks to our collaborators of the project, Dr. B. Maji, Dr. S. Srivastava, Dr. A. Subba Rao, IISS, Bhopal, Dr. Biswapati Mandal, BCKV, Mohanpur, Dr. Dhanwinder Singh, PAU, Ludhiana; Dr. Murugesa Boopathi and Dr. R. Natesan, TNAU, Coimbatore, Dr. [illegible] Lakshmi, ANGRAU, Bapatla, and Dr. M. N. Patil and Dr. R.N. Katkar, PDKV, Akola for timely and successful execution of the project work.

I also take this opportunity to thank to all project workers, laboratory and field staffs involved in the project, specially Dr. R. S. Sisodia, Dr. Manik Kundu, Mrs. Gayathri, Mrs. Sangeetha, Mr. A.M. [illegible], Mr. B. Kumar, Mr. D.R. Darwai and Mr. Kalicharan. I also owe a lot to my Divisional colleagues, other scientists of the Institute, Administrative Officer, Assistant Finance and Account Officer and other office staffs for their help, interactions and suggestions during the course of the project.

Date: December 23, 2010

(A.K. Biswas)
Principal Investigator

1. Introduction

Producing an adequate quantity of healthy food without polluting the environment is a formidable challenge for future agriculture in the world. About 26 million tonnes of atmospheric nitrogen is being fixed every year globally. The global mean use efficiency of applied N is estimated to be less than 50 per cent, and the remaining quantity of nitrogen is lost into the environment. A large proportion of this nitrogen gets converted into nitrate which, being soluble in water and not retained by soil, gets leached into water bodies. Leaching of nitrate from agricultural land and from other sources to groundwater is a global phenomenon. Since the 1960s, nitrate loading in both surface and ground water have drawn great attention worldwide. Nitrate pollution cases that exceed the threshold as recommended by the World Health Organization (50 mg NO_3^- L^{-1}) and by the USA (10 mg NO_3^- -NL^{-1}) for drinking water have been reported in many countries, such as UK, Denmark, Belgium, France (Strebel et al., 1989; Fried, 1991), USA (Nolan et al., 1997; [illegible], 2000) and India (Agrawal et al., 1999). The agriculture derived nitrate pollution of groundwater has become an environmental issue which may cause algal blooms and eutrophication in ecosystems, and even produce potential hazards to human health (Knobe-loch et al., 1992; Gulis et al., 2002). The heavy use of nitrogen (N) fertilizer for intensive farming and cropping systems with low N use efficiency are often responsible for nitrate accumulating into groundwater (Strebel et al., 1989). Observed pollution may be the consequence of farming practices many years ago rather than current practices and hence the pollutant source may not spatially and temporally coincide with the polluted site (Singh and Sekhon, 1978; Mutch, [illegible]).

The fertilizer consumption in the country has made significant growth during the last three decades and presently the level has gone up to about 17.8 million tonnes of NPK per annum out of which more than 65 per cent is nitrogenous fertilizer. In terms of fertilizer production India ranks third after China and USA. The average plant nutrient consumption of the country is only 106 kg ha^{-1} yr^{-1}, which is markedly less as compared to other countries, like Netherland (501 kg), South Korea (450 kg), U.K. (345 kg) and China (271 kg). Fertilizer consumptions even in the neighbouring countries like Bangladesh and Pakistan are higher, *i.e.*, 154 and 120 kg ha^{-1} yr^{-1}, respectively, than that of India (Fertilizer Statistics, 2005-'06). However the distribution and application of fertilizer are not uniform throughout the country. For example, more than 75% of total fertilizer N is used only in 165 out of total number of districts in India and some crops and cropping sequences like rice-wheat, rice-rice, rice-potato and orchards receive very heavy fertilizer application, especially nitrogenous fertilizer. Moreover, there is regional disparity in terms of fertilizer consumption and nutrient consumption ratio. Whereas 46 out of 146 districts (31%) of the north zone of the country use more than 150 kg fertilizer ha^{-1} yr^{-1}, only 4 out of 131 districts (31%) of the west zone of the country consume more than 150 kg fertilizer ha^{-1} yr^{-1}. Similarly, in the north zone of the country the nutrient consumption ratio since 2000-01 has been highly skewed in favour of nitrogenous fertilizers ($N:P_2O_5:K_2O$ = 29:8.5:1) as compared to those in south (3.8:1.7:1), east (4.5:1.6:1) and west zones (7.2:3.4:1) (Fertilizer Statistics, 2005-'06). Hence, it becomes increasingly important to seriously consider fertilizer induced environmental pollution especially contamination of groundwater with excessive leaching of nitrate in intensively fertilized areas of the country.

Nitrates are derived not only from nitrogenous fertilizers but also from organic manures, and human and animal wastes. It is known that apart from manures and fertilizers many other industrial and anthropogenic activities can cause nitrate pollution in aquifers. These sources are: Direct point sources - transfer of pollutants from municipality, industrial liquid waste disposal sites and refuse disposal sites; Diffuse agricultural sources - wash-off and soil erosion from agricultural lands carrying materials applied during agricultural use, mainly fertilizers, herbicides and pesticides; and Diffuse urban sources - runoff from city streets, from horticultural gardening and commercial activities in the urban environment and from industrial sites and storage areas.

Nitrate is the most ubiquitous chemical contaminant in the world's aquifers and the levels of contamination are increasing (Spalding and Exner, 1993). Nitrate leaching and water contamination have become a major concern worldwide mainly due to the intensification of agricultural production system involving the application of N fertilizers and organic wastes in the past 50 years. The magnitude of nitrate leaching is, however, dependent on soil characteristics, cropping pattern, fertilizer management practices (rate, source and timing of application) and irrigation. The problem of nitrate leaching and the contamination of ground and surface waters are particularly severe in developed countries, where economically viable agricultural production has involved heavy use of N fertilizers and organic wastes (Addiscott, 1996; Cameron et al., 1997; Spalding and Exner, 1993). Many agricultural systems in developing countries like India are still N deficient for optimum production. Recently, however, rising nitrate concentrations have been detected in some regions of India where agricultural production has intensified with increasing use of chemical and organic fertilizers (Singh et al., 1995). In agriculturally intensive areas in Punjab (Singh et al., 1995; Bajwa et al., 1993), Haryana (Bijay-Singh and Singh, 2004) Delhi (Gupta and Chandrasekharan, 1999), Maharastra (Despande at al., 1999), and Andhra Pradesh (Srinivasa Rao, 1998), where fertilizer applications are high, pollution of groundwaters by nitrate have been reported. Several other studies have also reported groundwater contamination by nitrate due to agricultural activities (Mukherjee and Pandey, 1994; Chandu et al., 1995; Prasad, 1998). High concentrations of nitrate in the groundwater samples were attributed to animal and human sources or irrigation return flows from agricultural fields dressed with fertilizers. Rajmohan et al. (1997) reported that irrigation return flow has increased the ionic concentration in groundwater of Nagai Quaid-E-Milleth district of Tamil Nadu, India. Tamta et al. (1991) reported that groundwater samples collected from dugwells in Godavari basin, Karnataka contained a mean nitrate concentration of 80.9 mg l^{-1}(range: 10-205 mg l^{-1}), which was attributed mainly to application of chemical fertilizers.

High concentration of nitrate in drinking water is deemed harmful to human health particularly for infants, because it can interfere with the transport of oxygen in the blood causing methemoglobinemia (blue body syndrome). Possible links between nitrate intake in drinking water and stomach cancers in adults and childhood diabetes have also been reported (Addiscott, 1996). High concentration of nitrate in drinking water is also toxic to livestock and can cause methemoglobinemia and abortion in cattle. Nitrate drained into surface water bodies, e.g. rivers, lakes or estuaries can also cause deterioration of surface water quality resulting in eutrophication, algal bloom and fish poisoning. Due to these health risks, a great deal of emphasis has been given to identify the sources of nitrate pollution and evaluate relative contribution of different sources so that preventive measures may be taken to help alleviate the problem. Numerous reports have linked increased use of nitrogenous fertilizers with nitrate pollution in ground water, although enough data base has not been created to ascertain this linkage or otherwise.

Non-point source pollutants like nitrate are transported from the land by surface water and groundwater pathways, since the pollutant source cannot be attributed to one particular discharge location rather to a large area. Specific vulnerability to agricultural system is a function of contaminant factors such as the quantity, rate, timing, and methods of nitrogen application, irrigations, and other agriculture management characteristics. Intrinsic susceptibility is a function of hydro-geologic factors such as proximity of an aquifer to the land surface, hydrologic properties of soil, and the amount, timing, and location of aquifer recharge (Zaporozec, 1994). So far there has not been any systematic attempt to find out the extent of nitrate pollution in different soils and water resources of the country and to quantify the contribution of the above factors towards nitrate contamination of aquifers. A critical evaluation of the existing status suggests that there is a need for systematic investigation of the occurrence and behavior of nitrate in grand water to design effective mitigation and management strategies. In view of this background, a detailed study of nitrate contamination in ground waters of intensive agricultural areas of six highly fertilized and intensively cultivated districts of the country, namely, West Godavari, Ferozepur, Hooghly, Jalgaon, Coimbatore and Hoshangabad was taken up during pre- and post-monsoon seasons of 2005-06 and 2006-07 with the following objectives.

2. Objectives

- To study the extent of nitrate contamination in soil and water in selected districts.
- To study temporal variation in the NO$_3$-N content in the representative aquifers of the selected sites.
- To study the distribution of NO$_3$-N in the soil profiles of the selected sites.
- To evaluate the vulnerability of soil and water to nitrate contamination in the selected districts.

3. Study Area

The study area encompassed six intensively cultivated districts of the country having medium to very high fertilizer usage with varying climate, soil type and crops and cropping systems (Table 3.1). Apart from the sources of pollution, fertilizer usage, climate, soil type, cropping pattern are some of the important factors affecting nitrate pollution of groundwater. These districts were chosen to bring about variability in these factors so as to evaluate and delineate the contribution of different factors in affecting nitrate pollution in ground waters.

3.1 Background of the target districts

3.1.1 West Godavari

West Godavari is the pioneering district in Andhra Pradesh in adopting latest technologies in agriculture, in achieving higher production and productivity. It is treated as rice bowl of Andhra Pradesh (Fig.3.1). The West Godavari district was formed in the year 1925. It lies between 16°15' and 17°30' of the northern latitude and 80°55' of the eastern longitude. The total population of the district is 3803517 (2001 census). It can be divided into three natural regions, namely, delta, upland and agency areas. It has an area of 7,742 square kms. It has four revenue divisions namely Eluru, Kovvuru, Jangareddigudem and Narasapur having number of revenue mandals 16, 12, 6 and 12 respectively i.e., total 46 mandals. The climatic condition of the district comes to an extreme type under temperate zone with high to very high temperatures in summer to an extent of 48°C and fairly cool climate towards hilly area or Polavaram and adjoining parts of Bay of Bengal in southern part of the district. The district normal rainfall is 1153.mm. and average 979.1 mm. The type of soils

Table 3.1: Fertilizer statistics and some other parameters/situations of the target districts

Sl. No.	Name of the district	Fertilizer consumption ($N+P_2O_5+K_2O$)			Climate	Soil Type	Crops/ Cropping System
		Mg	kg ha^{-1}	Rank*			
1	West Godavari (A.P.)	224110	316.1	2	Hot sub humid	Deep loamy coastal and deltaic alluvial	Rice –rice (shallow rooted)
2	Ferozepur (Punjab)	179961	209.4	4	Hot semiarid	Deep loamy alluvial to shallow to medium sandy	Rice-wheat, pulses (shallow vs. deep)
3	Jalgaon (Maharashtra)	166762	114.9	9	Hot semiarid	Shallow and medium clayey black soil	Sorghum, Sorghum, cotton, pulses and vegetables (shallow vs. deep rooted)
4	Hooghly (W.B.)	145602	275.4	13	Hot perhumid	Deep loamy alluvial	Rice- wheat – potato ,rice-rice (shallow vs. deep rooted)
5	Coimbatore (T.N.)	61749	185.2	117	Hot Semiarid	Shallow to deep loamy red or black soil	Rice/ millet pulses/ oilseed (shallow vs. deep rooted)
6	Hoshangabad (M.P.)	54477	115.0	147	Hot sub humid	Medium to deep clayey black soil	Soybean/ vegetables / wheat /pulses (shallow vs. deep rooted)

* Ranking in terms of total fertilizer consumption

of the district are grouped as red, sandy clay loams, alluvial sandy loams, deltaic alluvial, coastal sandy loams, heavy clays and saline soils. The net area cultivated forms about 57.4 per cent of the total geographical area of the district. The principal crops grown in the district are - paddy, sugarcane, cotton, groundnut, maize, jowar, pulses (green gram, blackgram, redgram and horsegram), chillies, tobacco and horticultural crops like turmeric, vegetables and fruit crops like mango, coconut, banana, orange, lemon and oilpalm.The total fertilizer consumption (2006-07) of the

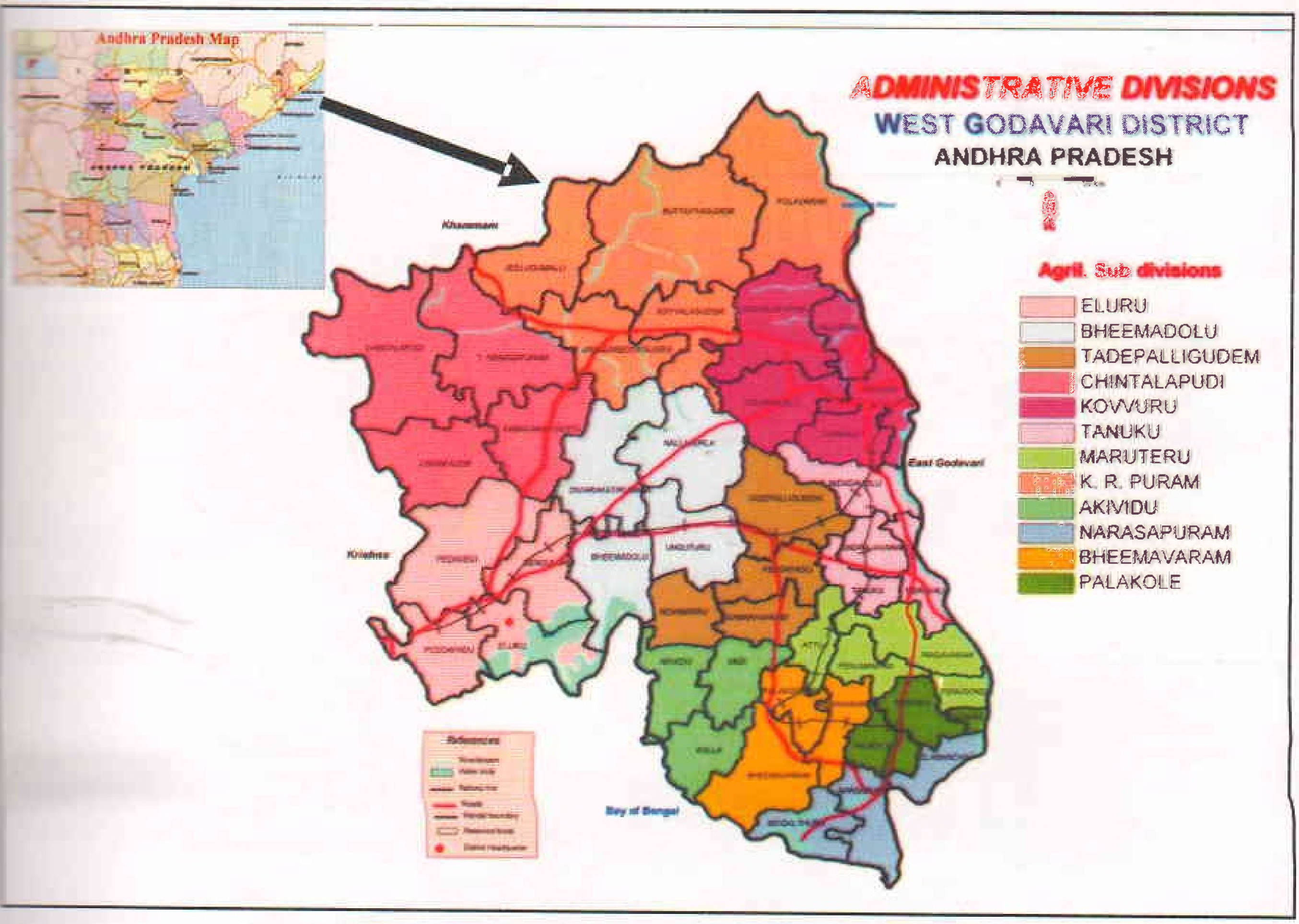


Fig.3.1: Location map of West Godavari district of Andhra Pradesh

district is 224110 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 316 kg ha^{-1}. The district ranks 2nd in terms of total fertilizer consumption (Fertilizer Statistics, 2006-07).

3.1.2 Ferozepur

The study area (Ferozpur district of Punjab) is located between 30°55'N latitude and 74°37'E longitude with an elevation of 190 m covering an area of 585 thousand hectares with 10 blocks having fully irrigated agriculture (Fig.3.2). The soil types of the districts are Typic Haplustept and Typic Ustipsamnents with medium to heavy texture. Paddy, wheat and cotton are the most important crops of the target district, and rabi oilseeds, sugarcane, barley and gram are also grown in some pockets. The total fertilizer consumption (2006-07) of the district is 179681 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 209 kg ha^{-1}. The district ranks 4th in terms of total fertilizer consumption (Fertilizer Statistics 2006-07).

3.1.3 Hooghly

The study area (Hooghly district of West Bengal) is located between 22°39'32"and 28°10'20"N and 88°30'15"and 87°30'20"E covering an area of 3149 sq. km. with 5.04 million population (2001 census) (Fig. 3.3). The district is divided into three subdivisions with 17 agricultural blocks. Rice and potato are its principal crops. The climate of the district is hot moist sub humid with an annual mean temperature of 26.8°C (although monthly mean temperatures range from 16°C to

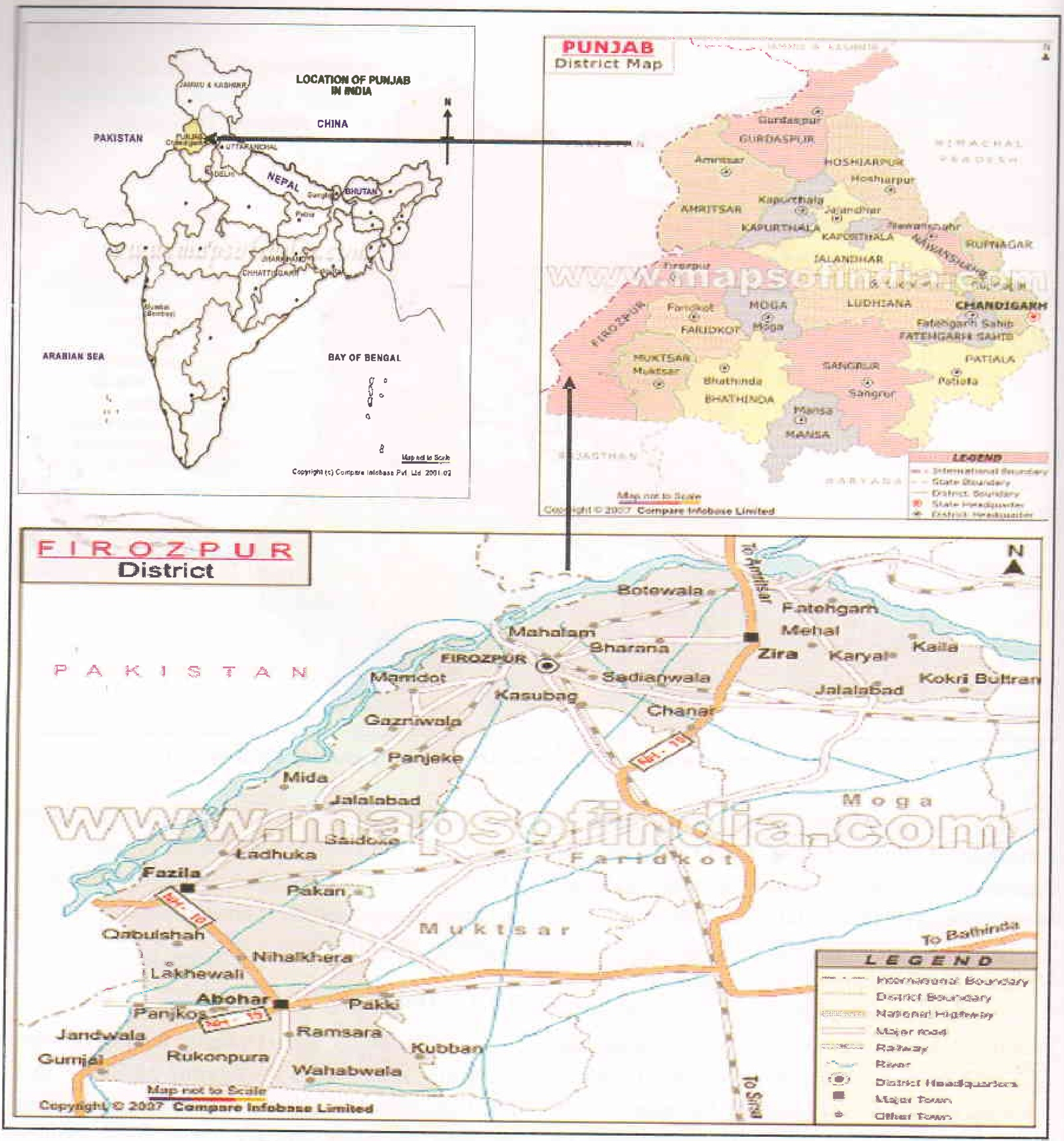


Fig. 3.2: Location map of Ferozepur district of Punjab

33°C) and a precipitation of 1599 mm. The soils of the district belong to three orders, with Inceptisols covering 64.4%, Entisols 23.1% and Alfisols 12.4% of the total area. The total thickness of the groundwater aquifers varies from 27 to 30 m and they mostly occur in the semi-confined state. It is one of the most intensively cultivated and heavily fertilized districts of the country and of West Bengal with high agricultural productivity. The sources of irrigation are open wells, tube wells,

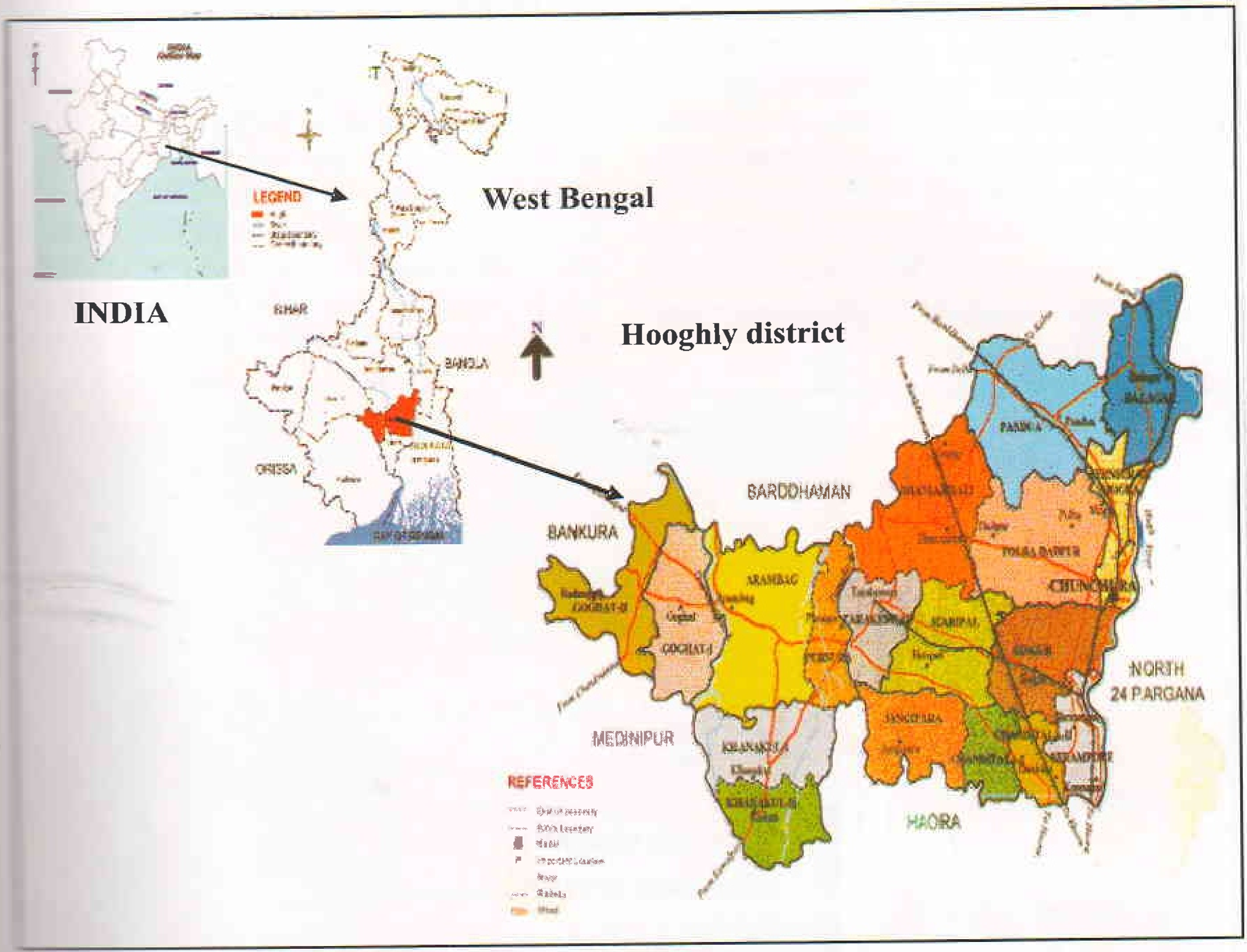


Fig.3.3: Location map of Hooghly district of West Bengal

shallow tube wells, mini deep tube wells, deep tube wells and lift irrigation from river and canals which leads to heavy utilization of chemical fertilizers. The total fertilizer consumption (2006-07) of the district is 145602 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 275.4 kg ha^{-1}. The district ranks 13th in terms of total fertilizer consumption (Fertilizer Statistics 2006-07). The cropping intensity is as high as 215%.

3.2.4 Jalgaon

Jalgaon is located on the north of Maharashtra state and bordering Madhya Pradesh on the north side, to the east Buldhana district, Aurangabad district to the south, Nasik district on the south-west and Dhule district on the west (Fig. 3.4). It lies between 20° to 21°N latitude and 74°55' to 76°28' E longitude. The district is having the geographical area of 11,63,898 ha, while the area under cultivation is 8,54,299 ha out of which 1,43,871 ha is under irrigation. The district is surrounded by Satpura mountain on north side and Satmala and Ajanta ranges in the south. Due to this, physiography of the district shows various landforms viz. hilly terrain, escarpment, plains and river basins. Geologically, Jalgaon district has basaltic rock. The drainage pattern of the district indicates major river Tapti that flows from east to west with its main tributaries like Purna, Girna, Wagur, etc. The Jalgaon district is famous for

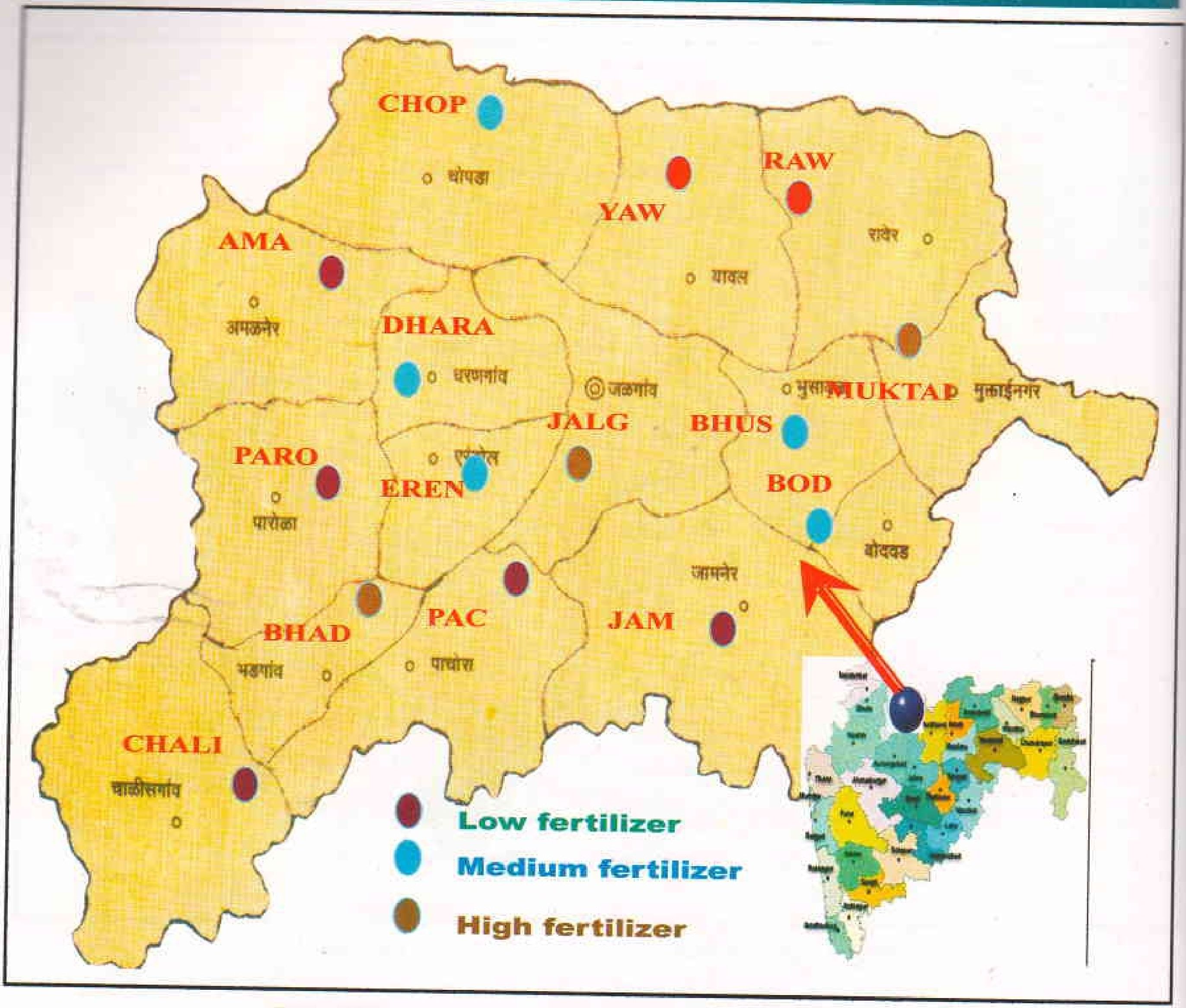


Fig.3.4: Location map of Jalgaon district of Maharashtra

banana cultivation in Maharashtra as well as in India. Besides, banana, many field crops like cotton, sugarcane, jowar, bajara, sunflower, safflower, green gram and vegetables are grown in the district. The sources of irrigation are open wells, tube wells, and lift irrigation from river and canals which leads to heavy utilization of chemical fertilizers. The banana crop is mainly irrigated through drip irrigation system in the district. The district consists of 15 tehsils. The total fertilizer consumption (2006-07) of the district is 166762 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 114.kg ha^{-1}. The district ranks 9th in terms of total fertilizer consumption (Fertilizer Statistics 2006-07).

3.1.5 Coimbatore

Coimbatore is an inland district bordering Kerala state on the west and South Nilgiris and Erode district on the North, and Erode and Dindigul districts on the East. It lies between 10°12'and 11°24' N latitude and between 76°36' and 77°30' E longitude (Fig. 3.5).

The district has a total area of 7, 46, 799 ha. The district consists of 9 talukas and 21 blocks. It is bounded by the western Ghats, of which the Nilgris on the north west and Anamalai on the south are the chief ranges that attain a height of over 2,400 m. In between the hill ranges lies the east-west trending pass known as Palghat gap. The rest of the district is an undulating plain sloping gradually from west ([illegible]) to east (150m).The tributaries of the Cauvery namely the Noyyal and Amaravathi run through the district and are east flowing. There are smaller rivers like Aliyar, Sholaiyar, Parambikulam and Palar originating in the Anamalai hills and flowing westwards. The total fertilizer consumption (2006-07) of the district is 61749 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 185.2 kg ha^{-1}. The district ranks 117th in terms of total fertilizer consumption (Fertilizer Statistics, 2006-07)

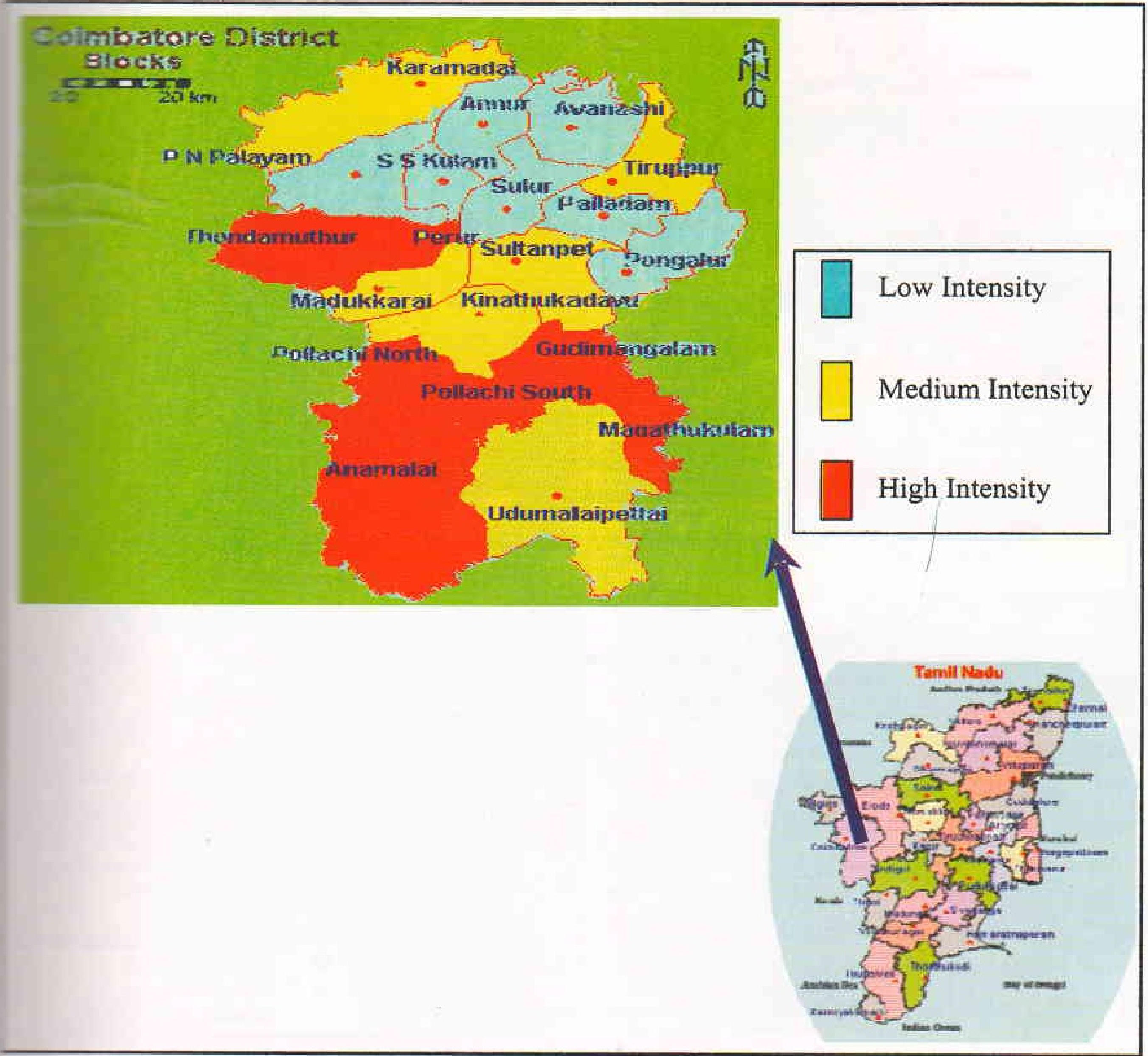


Fig. 3.5:Location map of Coimbatore district of Tamil Nadu

the district is neither too hot nor too cool except the winter season in Pachmarhi, a famous hill station of the state. Soybean and wheat are the most important crops of the district, while paddy, maize, gram, vegetables, pigeon pea and sugarcane are also grown at different pockets.

In Hoshangabad, there is a network of irrigation canals under the Narmada-Tawa command area through which the majority of areas of the district is irrigated. There is a preponderance of open well in the blocks of Hoshangabad, Seoni-malwa and Babai, which are under the influence of Narmada-Tawa command. The depth of water table is also quite low in these blocks. Open wells and tube wells are used both for drinking and irrigation purposes and are well distributed in the crop field and residential areas. On the other hand, hand pumps are mostly located in the residential and community areas, and are mostly used for drinking water purposes. The total fertilizer consumption (2004-05) of the district is 510288 tonnes and the average fertilizer consumption rate ($N+P_2O_5+K_2O$) is 103.5 kg ha^{-1}. The district ranks 147th in terms of total fertilizer consumption as per Fertilizer Statistics (2006-07).

Plate 1 : Sources of ground water samples from Hoshangabad

4. Sampling Scheme

Soil and water samples were collected during pre-monsoon and post-monsoon period of 2006 and 2007. Stratified random sampling strategy was adopted and as per sampling strategy a ratio of 6:3:1 or 4:2:1:: high: medium : low was maintained so as to collect more samples from areas of higher fertilizer usage and proportionately less samples from areas of lower fertilizer usage (Fig.4.1). Apart from collecting soil and water samples, a detailed survey was made of all the sampling sites with respect to cropping, irrigation, nutrient management, etc through a questionnaire. A detailed sampling scheme for each district is given hereunder:

4.1 West Godavari

Water samples were collected during the pre- and post-monsoon seasons of 2006 and 2007 from open wells, tube wells and hand pumps at 480 odd sites in 48 villages spread over 20 mandals of the West Godavari district of Andhra Pradesh, and GPS was used for recording the geographical position of each of the sampling spots (Fig. 4.2). The sampling was done following a ratio of 4:2:1 for high (> 300 kg ha^{-1}) medium (200-300 kg ha^{-1}) low (< 200 kg ha^{-1}) fertilizer consumption rate and as such a total of 480 samples were collected in the each of the three seasons (Table 4.2). While selecting the wells, preference was given to those, which are used as sources of water both for irrigation and drinking purposes. Samples were collected in acid washed polythene bottle and care was taken to collect the samples after allowing the wells to flow for few minutes before collecting the samples. Few drops of purified H_2SO_4 was added to each polythene bottle before collecting the samples to bring the sample pH down to 2 or less for preserving it for determination of NO_3-N through Flow Injection Analyzer (FIA) while pH and EC values of the samples were measured *in-situ* immediately after collection.

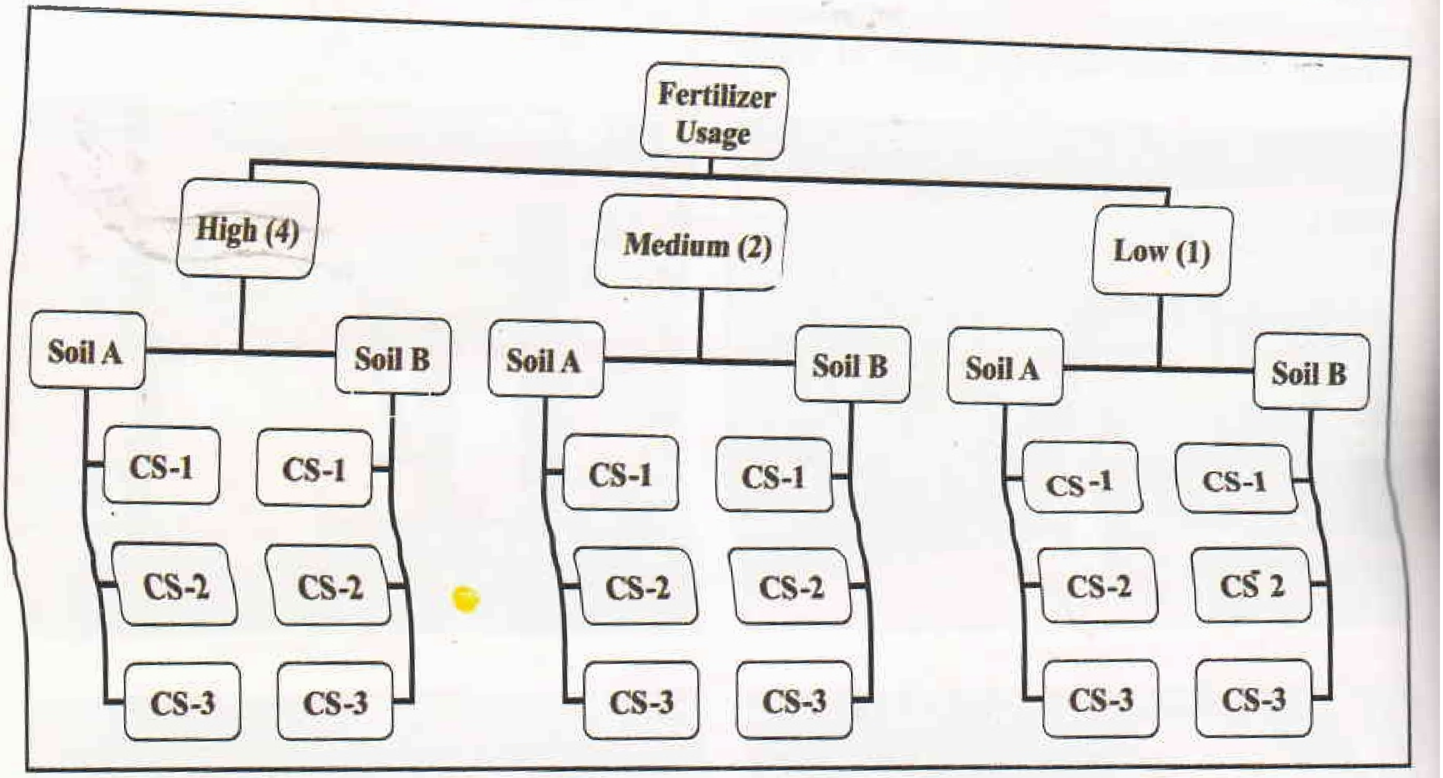


Fig. 4.1: Soil and water sampling scheme tree for the District

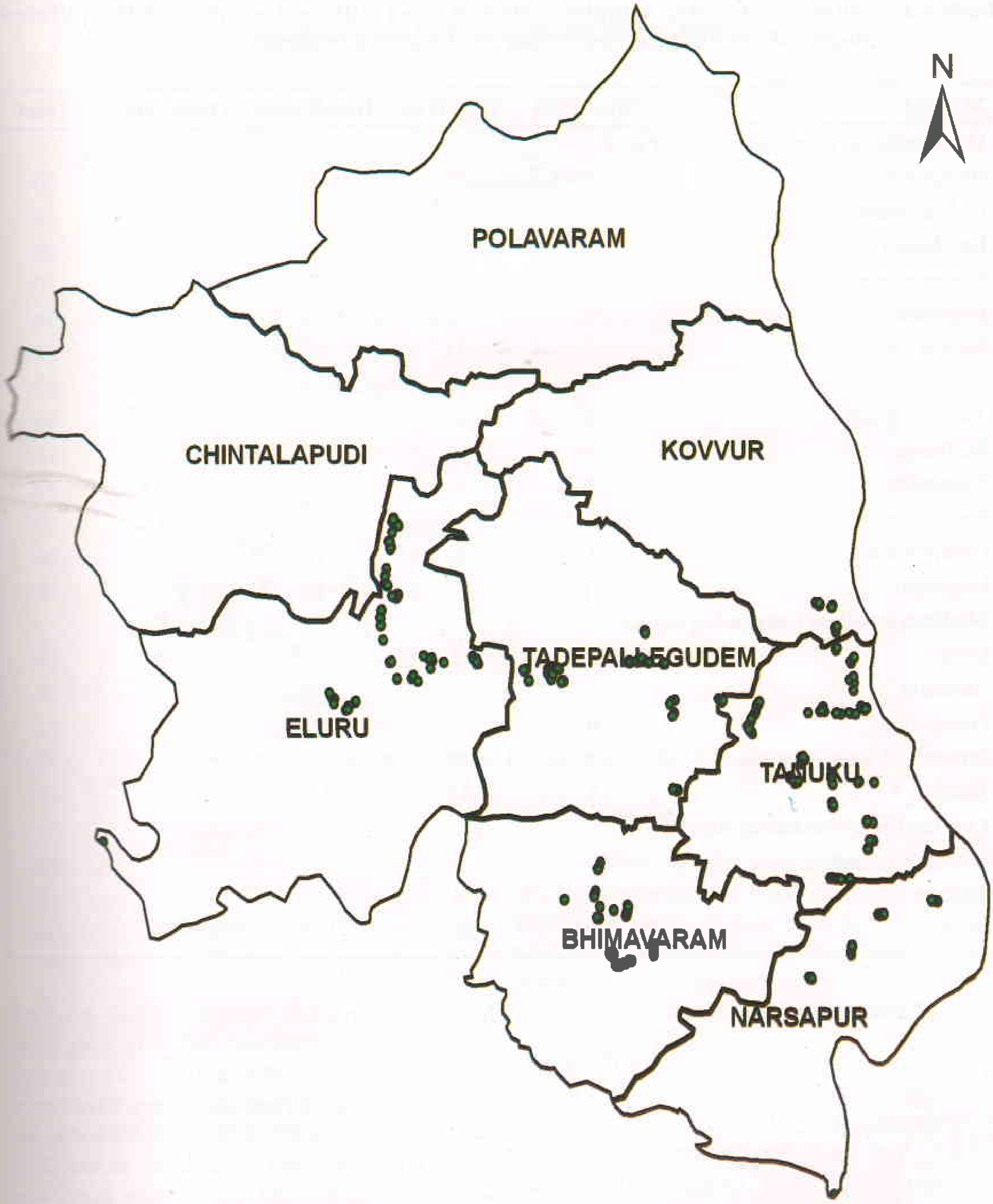


Fig.4.2: Geo-referenced water sampling points of pre-monsoon 2007 in a digitized map of West Godavari district

Table 4.1: Number of water samples collected from different sources of the different blocks of the West Godavari district of Andhra Pradesh

Mandal	Open Well	Tube Well	HandPump	Other Source	Total
High fertilizer consuming blocks					
Bhimadolu	2	20	7	1	30
Bhimavaram	16	-	2	2	20
Denduluru	1	18	1	-	20
Ganapavaram	3	-	7	-	10
Iragavaram	9	2	19	-	30
Nidadavolu	2	11	6	1	20
Poduru	4	6	10	-	20
Tadepalligudem	4	29	7	-	40
Palakollu	8	1	1	-	10
Pentapadu	2	-	18	-	20
Penumantra	2	-	5	3	10
Undrajavaram	1	21	8	-	30
Unguturu	11	32	5	2	50
Medium fertilizer consuming blocks					
Undi	10	3	13	4	30
Atchanta	-	-	10	-	10
Penugonda	6	7	7	-	20
Peravali	2	18	-	-	20
Tanuku	3	17	10	-	30
Low fertilizer consuming blocks					
Dwaraka Tirumala	17	24	7	2	50
Kalla	4	4	2	-	10
Total	107	214	145	14	480

4.2 Ferozepur

After the preliminary survey of the target district, first soil and water sampling was started. For conducting this, 10 villages were selected randomly from each development block of the Ferozepur district. Thus 50 villages were selected randomly from 10 development blocks of Ferozepur district. From each village 10 water samples were collected from the running tube wells by stratified random sampling during pre- and post-monsoon of 2006 and 2007 (Fig. 4.4). From each village one soil sample (along with tube well water sample used for irrigation) from three depths *i.e.* 0-20, 20-40 and 40-60 cm was collected by the use of post hole auger. Thus in all almost 2000 water samples and 200 soil samples depth-wise were collected from the target district Ferozepur. GPS was used for recording the geographical position of each of the sampling spots (Fig. 4.3).

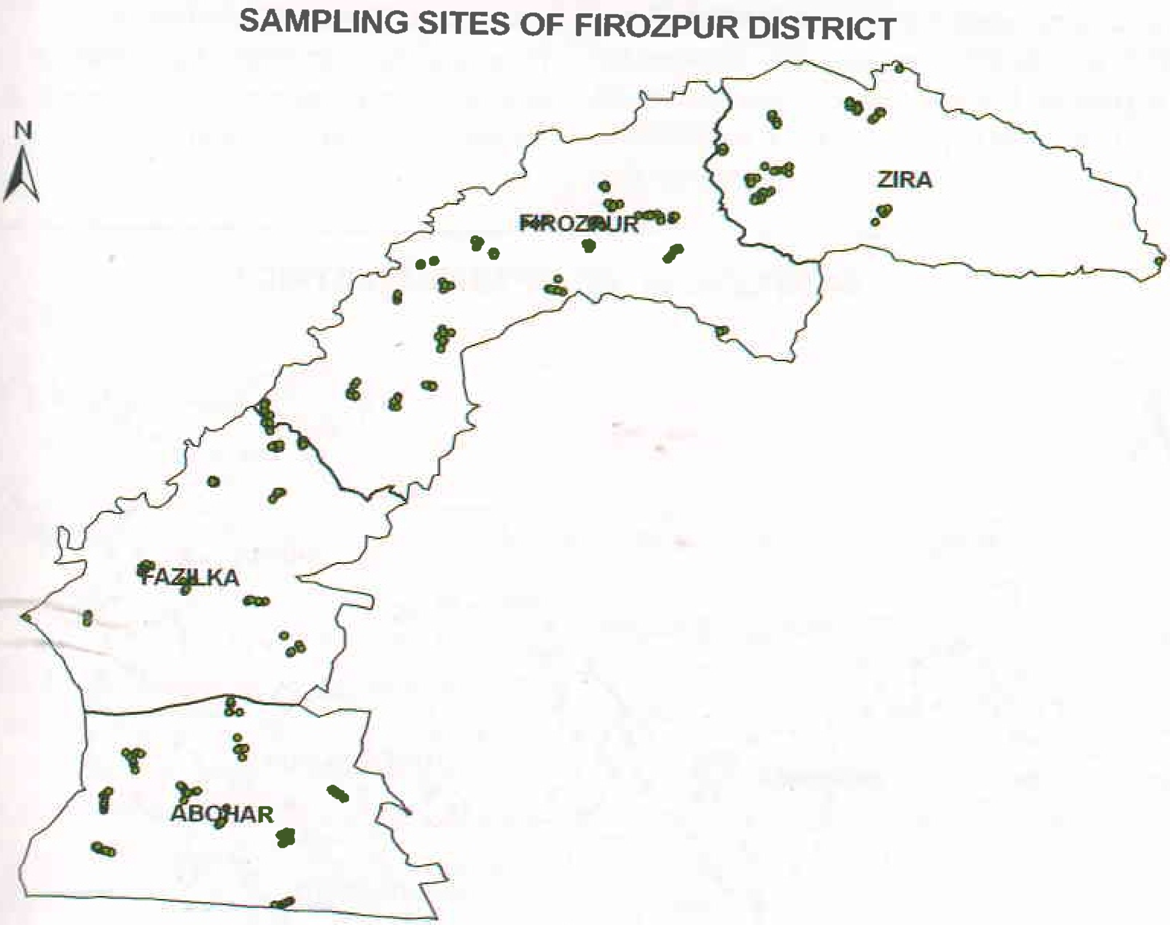


Fig. 4.3: Geo-referenced water sampling points of pre-monsoon 2007 in a digitized map of Ferozepur district

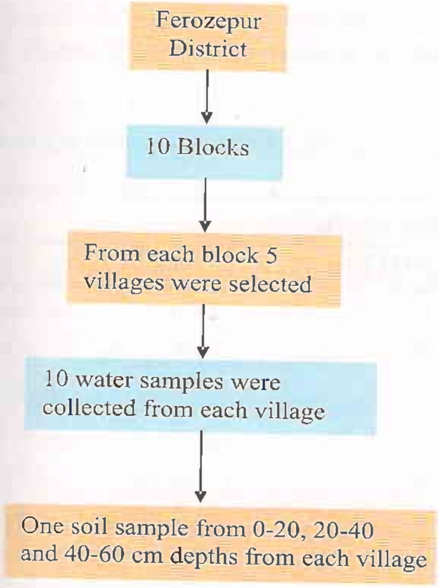

Ferozepur District
10 Blocks
From each block 5 villages were selected
10 water samples were collected from each village
One soil sample from 0-20, 20-40 and 40-60 cm depths from each village

Fig. 4.4: Soil and water sampling scheme tree

4.3 Hooghly

Water samples were collected during the pre- and post-monsoon seasons of 2006 and 2007 from open wells, shallow tube wells, mini deep tube wells and deep tube wells at 412 odd sites (villages) spread over 17 blocks of the Hooghly district of West Bengal and GPS was used for recording the geographical position of each of the sampling spots (Fig. 4.5). As there was almost no variation in average fertilizer consumption of the 17 blocks, all these blocks were not divided in low, medium and high category blocks and as such a total of 858 number of samples were collected in the each of the three seasons (Table 4.2). While selecting the wells, preference was given to those, which were used as sources of water both for irrigation and drinking purposes. Samples were collected in acid washed polythene bottle and care was taken to collect the samples after allowing the wells to flow for few minutes before collecting the samples. Few drops of purified H_2SO_4 was added to each polythene bottle before collecting the samples to bring the sample pH down to 2 or less for preserving it for determination of NO_3-N through Flow Injection Analyzer (FIA) while pH and EC values of the samples were measured *in-situ* immediately after collection.

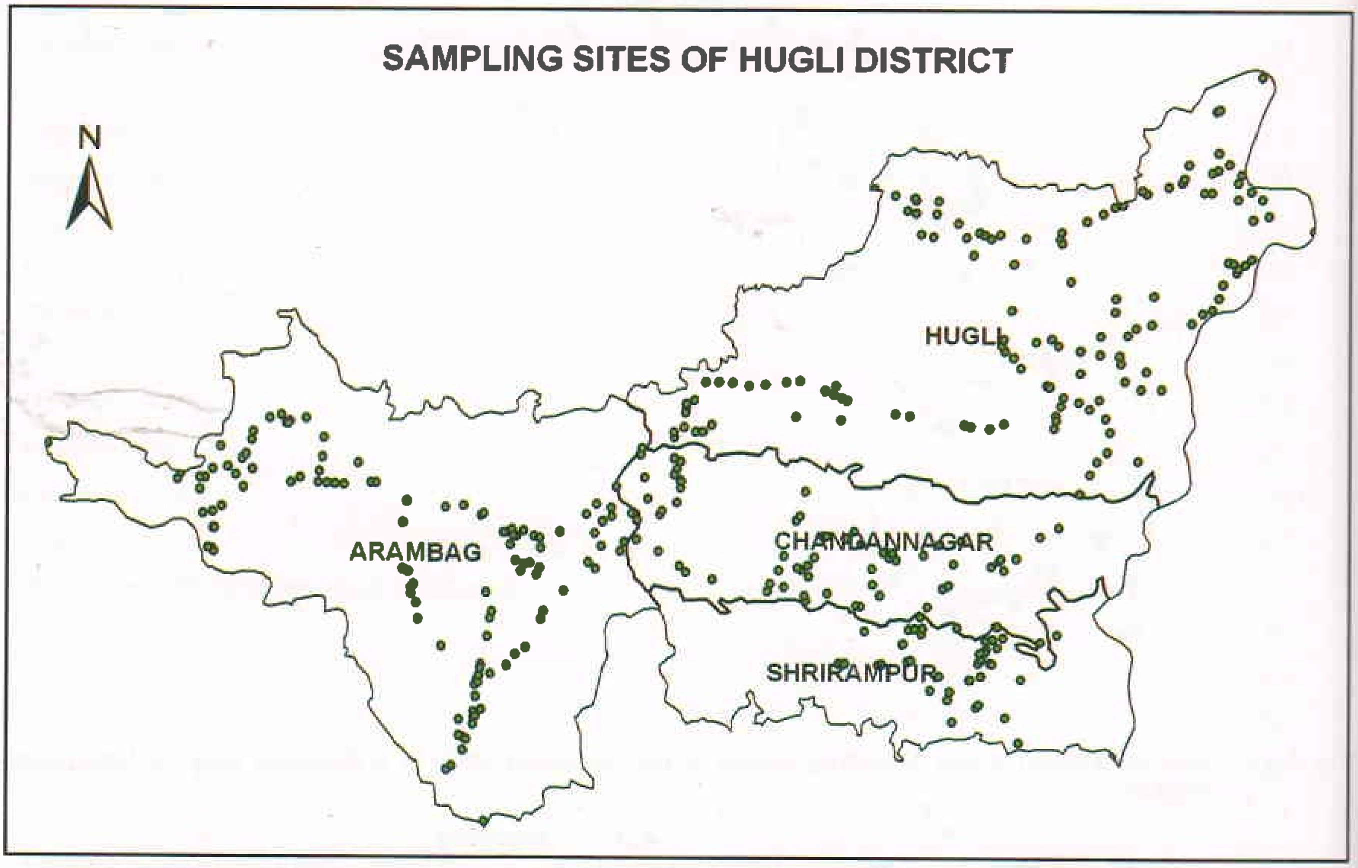


Fig.4.5: Geo-referenced water sampling points of pre-monsoon 2007 in a digitized map of Hooghly district

Table 4.2: Number of water samples collected from different sources of the different blocks of the Hooghly district of West Bengal

Block	Sources of water sampling					
	Well	TW	STW	MDTW	DTW	Total
Mogra	1	17	6	0	5	29
Balagar	2	46	17	5	8	78
Pandua	1	35	20	7	7	70
Polba	1	35	22	4	7	69
Chanditala-I	0	25	15	2	2	44
Chanditala-II	0	21	15	2	4	42
Singur	1	28	14	1	4	48
Haripal	0	42	17	5	3	67

Block	Sources of water sampling					
	Well	TW	STW	MDTW	DTW	Total
Goghat-I	0	25	15	4	3	47
Goghat-II	0	26	15	5	8	54
Khanakul-I	0	17	10	3	3	33
Khanakul-II	0	17	11	3	2	33
Arambag	1	39	21	7	5	73
Tarakeswar	0	26	20	2	2	50
Pursura	0	22	12	3	5	42
Dhaniakhali	0	32	16	2	3	53
Jangipara	1	17	12	2	4	36
Overall		8	470	258	57	75

TW : = Tube Well ; STW : Shallow Tube Well ; MDTW : Midium Deep Tube Well ; DTW : Deep Tube Well

4.4 Jalgaon

As per the milestone of the project, water samples were collected from the Jalgaon district on the basis of block-wise fertilizer consumption (N + P_2O_5 + K_2O kg ha^{-1}). Blocks of the district were grouped as low fertilizer consuming (<100 kg ha^{-1}), medium fertilizer consuming (100-200kg ha^{-1}) and high fertilizer consuming (> 200 kg ha^{-1}) areas for collecting groundwater samples in the ratio of 1:3:6 along with 50 soil samples at a depth of 0-20, 20-40and 40-60cm. Blocks were divided into three categories on the basis of the fertilizer consumption as low (Pachora, Parola, Chalisgaon, Amalner and Jamner), medium (Dharangaon, Bhusawal, Erandol, Chopda, Bodwad) and high (Jalgaon, Yaval, Muktai Nagar, Raver and Bahdgaon). One village from each block was selected randomly for sampling of water and soil from low fertilizer consumption, three villages from each block in medium fertilizer consumption and six villages from high fertilizer consumption areas. In each village, ten water samples and one soil samples site (3 samples at each site 0-20, 20-40and 40-60cm depth) were selected. The sample sites were kept same to see the temporal (seasonal) variations. The target of 500 water samples and 50 soil samples sites (50 x 3 =150) was met in each season.

Water samples were collected during the pre-monsoon 2006 and pre- and post-monsoon seasons of 2007 from open wells, tube wells, hand pumps and lift (river) at 48 villages spread over 15 blocks of the Jalgaon district of Maharashtra and GPS was used for recording the geographical position of each of the sampling spots. Low, medium and high fertilizer consumption category in blocks and as such a total of 1306 number of samples were collected in three seasons. The water samples collected in the Jalgaon district during pre monsoon 2006, pre monsoon 2007 and post monsoon 2007 were 415, 426 and 465 respectively (Table 4.3). While selecting the wells, preference was given to those, which are used as sources of water both for irrigation and drinking purposes. In all 1306 water samples were collected from various sources, out of which 83 per cent (1083) and 15 per cent (190) water samples were collected from open well and tube wells, respectively, in all the seasons. Samples collected from different sources are given in Table 4.4.

Table 4.3: **Number of water samples collected from different sources of the different blocks of the Jalgaon district of Maharashtra.**

	Block	Open Well	Tube Well	Hand Pump	Lift (River)	Total
High	Bhadgaon	155 (95)	5 (3)	0	3 (2)	163
	Raver	73 (47)	76 (49)	0	6 (4)	155
	M'Nagar	131 (80)	27 (17)	0	5 (3)	163
	Yaval	125 (88)	15 (11)	1 (1)	1 (1)	142
	Jalgaon	137 (86)	13 (8)	8 (5)	2 (1)	160
	Total	621 (79)	136 (17)	9 (1)	17 (2)	783 (60)
Med	Bodwad	58 (98)	1 (2)	0	0	59
	Chopada	18 (31)	36(61)	5 (8)	0	59
	Erandol	85 (96)	4 (4)	0	0	89
	Bhusawal	80 (88)	9 (10)	0	2 (2)	91
	Dharangaon	89 (99)	1 (1)	0	0	90
	Total	330 (85)	51 (13)	5 (1)	2 (1)	388 (30)
Low	Pachora	30 (100)	0	0	0	30
	Parola	25 (93)	2 (7)	0	0	27
	40'Gaon	26 (10)	0	0	0	26
	Amalner	20 (95)	1 (5)	0	0	21
	Jamner	31 (100)	0	0	0	31
	Total	132 (98)	3 (2)	0	0	135 (10)
	G.Total	1083 (83)	190 (15)	14 (1)	19 (1)	1306

* Data in parenthesis indicate percentage of total

Table 4.4: **Water samples collected from different sampling aquifer depths in different seasons of Jalgaon district**

Source	Pre-M 06	Pre-M 07	Post-M 07	Total
Open Well	350	357	376	1083
Tube Well	51	61	78	190
Hand Pump	8	2	4	14
Lift (River)	6	6	7	19
Total	415	426	465	1306

4.5 Coimbatore

Coimbatore district consists of 20 blocks, namely, Annur, Avinashi, Periyanai-kenpalayam, Sarkarsamakulam, Madukkarai, Thondamuthur, Perur, Karamadai, Palladam, Sultanpet, Sulur, Anamalai, Kinathukadavu, Pollachi North, Pollachi South, Pongalur, Tirupur, Gudimangalam, Madathukulam and Udumalpet. For the purpose of sampling, blocks were divided in to low (Pongalur, Annur, Avinashi, Sarcarsamakulam, Palladam and

Sulur), medium (Periyanaickenpalayam, Karamadai, Kinathukadavu, Madukarai, Sulltanpet, Tirupur and Udulmalpet) and high (Perur, Thondamuthur, Anamallai, Pollachi-North, Pollachi-South, Gudimangalam and Madathukulam) intensity areas based on fertilization. The sampling was done following the ratio of 4:2:1 for high (>200 kg ha^{-1}), medium (100-200 kg ha^{-1}) and low (<100 kg ha^{-1}) fertilizer consumption rate. Water samples were collected during the post monsoon season of 2006, pre- and post-monsoon seasons of 2007 from open wells, bore wells and hand pumps at different villages spread over in the 18 blocks of the Coimbatore district of Tamil Nadu (Table 4.5). Due to the industrial influences, the information on samples from two blocks viz., Palladam and Tirupur, are not being reported. While collecting, GPS was used for recording the geographical position of each of the sampling spots. Using GPS geographical position of each of the sampling spot was noted (Fig. 4.6). Then the water samples were analysed for pH, EC and NO_3-N content (using Flow Injection Analyser). Horizon wise (0-20, 20-40 and 40-60 cm) soil samples were also collected from representative sites for their analyses for texture, pH, EC, and NO_3-N content to ascribe the possible causes for variation in the observed concentration of NO_3 in the water samples.

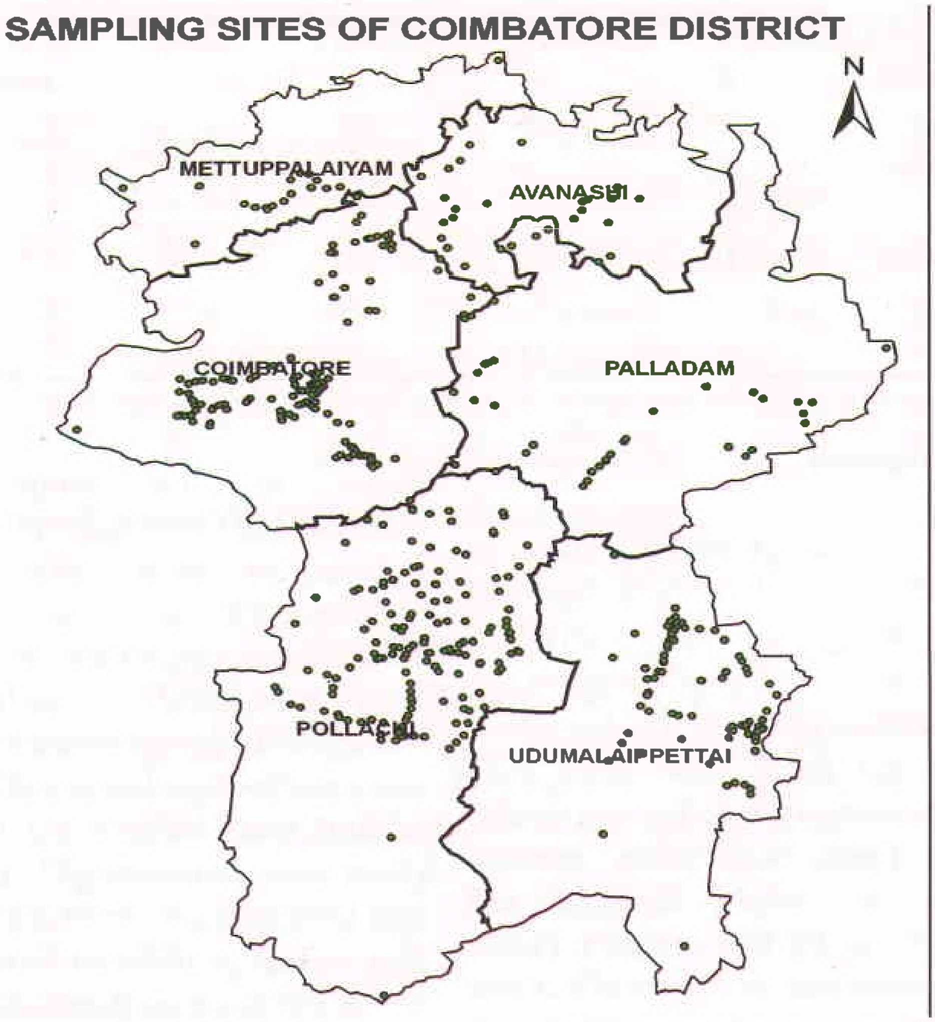


Fig.4.6: Geo-referenced water sampling points of pre-monsoon 2007 in a digitized map of Coimbatore district

Table 4.5: Number of water samples collected from different sources and locations of the different blocks of the Coimbatore district, Tamil Nadu

Block	Sources of water sampling					
	Well	TW	STW	MDTW	DTW	Total
Mogra	1	17	6	0	5	29
Balagar	2	46	17	5	8	78
Pandua	1	35	20	7	7	70
Polba	1	35	22	4	7	69
Chanditala-I	0	25	15	2	2	44
Chanditala-II	0	21	15	2	4	42
Singur	1	28	14	1	4	48
Haripal	0	42	17	5	3	67
Goghat-I	0	25	15	4	3	47
Goghat-II	0	26	15	5	8	54
Khanakul-I	0	17	10	3	3	33
Khanakul-II	0	17	11	3	2	33
Arambag	1	39	21	7	5	73
Tarakeswar	0	26	20	2	2	50
Pursura	0	22	12	3	5	42
Dhaniakhali	0	32	16	2	3	53
Jangipara	1	17	12	2	4	36
Overall	8	470	258	57	75	868

TW : = Tube Well ; STW : Shallow Tube Well ; MDTW : Medium Deep Tube Well ; DTW : Deep Tube Well

4.6 Hoshangabad

Based on the fertilizer usage at different blocks (Table 4.6), the district was stratified into three groups, that is, high (>125 kg ha^{-1}), medium (75-125 kg ha^{-1}) and low (<75 kg ha^{-1}). Three blocks, namely, Hoshangabad, Seoni-malwa and Babai were under high fertilizer usage category, whereas two blocks, Pipariya and Kesla, were under medium category, and two others, Bankhedi and Sohagpur, were under low category (Table 4.7). In order to evaluate the effects of soil type and cropping systems on nitrate contamination of ground waters, water sampling scheme was devised to collect samples representing different soil types under different crops and cropping systems. Also to account for various anthropogenic activities in contaminating groundwater with nitrate, sampling was done from various locations which were under the influence of crop production, habitation, dairy/poultry/agro-based industry, etc. A total of 2002 water samples and 200 soil samples (from three depths, i.e., 0-5, 15-30, and 30-45 cm) were collected from the district through four seasons in 2006 and 2007. GPS was used for recording the geographical position of each of the sampling spots (Fig. 4.7).

Table 4.6: Total fertilizer consumption (Mg) and rate of usage (kg ha^{-1}) in different blocks of the district (2004-05)

Block	N	P_2O_5	K_2O	Total (Mg)	Rate (kg ha^{-1})
Seoni-Malwa	9580	7457	521	17558	136.9
Kesla	1668	1310	89	3066	82.4
Hoshangabad	6574	5032	365	11971	157.3
Babai	3025	2413	611	6065	126.7
Sohagpur	1913	1796	113	3822	59.3
Pipariya	3247	1689	255	5191	90.8
Bankhedi	3609	1614	130	3353	58.1
Total	29616	21311	2084	510288	103.5

Table 4.7: Classification of blocks as per fertilizer usage

High (>125 kg ha^{-1})			Medium (75-125 kg ha^{-1})		Low (<75 kg ha^{-1})	
Hoshan-gabad	**Seoni -malwa**	**Babai**	**Pipariya**	**Kesla**	**Bankhedi**	**Sohagpur**
Soybean -wheat	Soybean -wheat	Soybean -wheat	Soybean -wheat	Soybean -wheat	Soybean -wheat	Soybean -wheat
Paddy -Wheat	Paddy -Wheat	Paddy -Wheat	Soybean -veg.	Maize -Wheat	Paddy -Wheat	Soybean -veg.
Soybean -veg.	Paddy -veg.	Paddy -gram	Maize -gram	Soybean -veg.	Sug arcane based	Soybean -gram

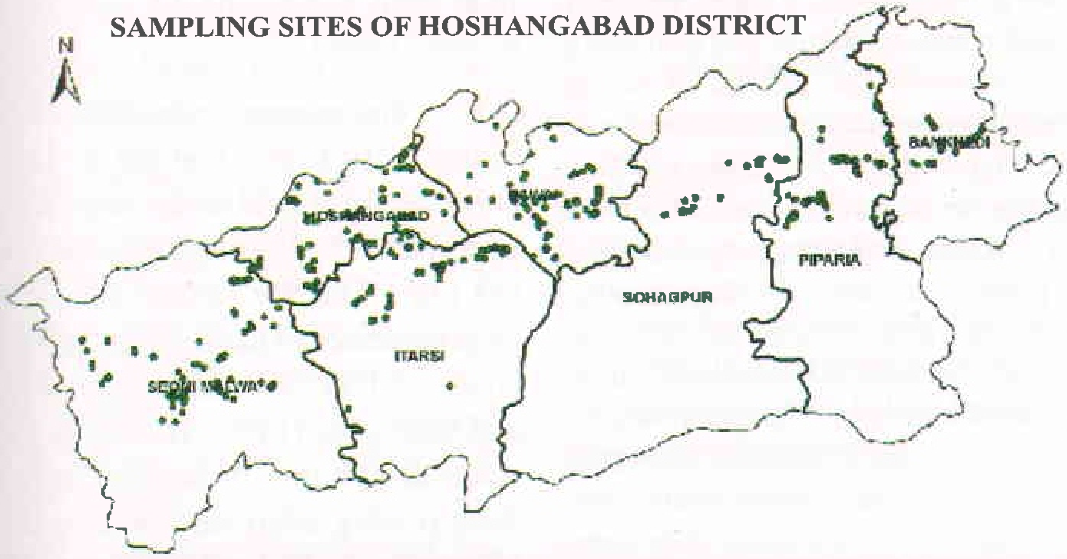


Fig.12: Geo-referenced water sampling points of pre-monsoon 2007 in a digitized map of Hoshangabad district

In Hoshangabad, there is a network of irrigation canals under the Narmada-Tawa command area through which the majority of areas of the district is irrigated. There is a preponderance of open well in the blocks of Hoshangabad, Seoni-malwa and Babai, which are under the influence of Narmada-Tawa command. The depth of water table is also quite low in these blocks. Open wells and tube wells are used both for drinking and irrigation purposes and are well distributed i crop field and residential areas. On the other hand pumps are mostly located in the resi and community areas, and are mostly used drinking water purpose. The number of samples from high, medium and low area 1139, 607, and 256, respectively (Table 4.8) pre- and post-monsoon of 2006 and 2007.

Table 4.8: Groundwater samples collected in different seasons

Intensity of fertilizer usage	Blocks	Pre-monsoon 2006	Post-monsoon 2006	Pre-monsoon 2007	Post-monsoon 2007	Total
High (1139)*	Seoni-malwa	93	99	100	100	392
	Babai	70	86	99	99	354
	Hoshangabad	105	90	99	99	393
Medium (607)	Piparia	87	84	80	80	331
	Kesla	47	71	79	79	276
Low (256)	Bankheri	64	33	35	35	167
	Sohagpur	9	20	30	30	89
Total		475	483	522	522	2002

* Data in parentheses indicate total number of water samples collected in four samplings

Nitrate pollution in water bodies generally happens through non-point sources and therefore it is difficult to ascertain the linkage of nitrate contamination to any particular source of water. In view of this, samples have been collected from different sources in proximity to or under the influence of various anthropogenic activities, namely crop production, habitation, dairy/poultry, etc. During pre and post-monsoon of 2006 and 2007, 1269 water samples were collected from sources in proximity to crop fields, 684 samples from habitation areas, and 49 samples having the influence of dairy/poultry/agro based industry, etc. 1040 water samples were collected from open wells, 537 samples from tube wells, 411 samples from hand pumps and 14 samples from sources (Table 4.9).

The source x location (Table 4.10) shows that out of 1260 collected from field areas, majority open wells (65.9%) and the rest to (34.1%). On the other hand, preponderance of hand pumps in the areas (58.1%) followed by open wells and tube wells (14%). There was equal distribution of samples dairy/poultry areas into open wells tube wells (27.1%) and hand pumps

Table 4.9: Number of water samples collected from different sources and locations

Block	Source				Location		
	Open well	Tube well	Hand Pump	Others	Field	Habitation	Dairy
Seoni-malwa	276	45	71	--	216	160	16
Babai	152	101	97	4	230	120	4
Hoshangabad	227	79	81	6	226	156	11
Piparia	116	132	82	1	207	115	9
Kesla	167	69	37	3	212	57	7
Bankhedi	43	91	33	--	109	56	2
Sohagpur	39	20	10	--	69	20	--
Total	1040	537	411	14	1269	684	49

Table 4.10: Number of water samples collected from different sources representing different anthropogenic activities

Location / Source	Field	Habitation	Dairy	Total
Open well	831 (65.9)	190 (27.9)	19 (39.6)	1040 (52.3)
Tube well	429 (34.1)	95 (14.0)	13 (27.1)	537 (27.0)
Hand pump	0	395 (58.1)	16 (33.3)	411 (20.7)
Total	1260 (63.3)	680 (34.3)	48 (2.4)	1988

Data in parenthesis indicate the per cent of total

5. Collection, Preservation and Analysis of Groundwater Samples

5.1 Well inspection

Before purging or sampling, all wells were inspected. Well depths were measured with the same instrument used to measure the water level. The surrounding soil and vegetation or other objects in the immediate vicinity of the well were inspected. Based on site-and well-specific information collected from the owner of the well, a decision was made regarding the number and depth of discrete, depth-specific, samples needed.

5.2 Order of sampling

In cases where water quality data were available, purging and sampling of wells began with the least contami-nated wells and proceeded to increasingly contaminated wells.

Where the distribution of contaminants is not known, purging and sampling activities began with wells considered to be upgradient from likely source(s) of contamination and finish with downgradient wells closest to suspected contamination.

Where application of the term "upgradient" could not be applicable and previous water quality data were not available, wells considered to be background wells were purged and sampled first.

5.3 Water-level measurements

Water level probes were deconta-minated by triple-rinsing with clean control water and drying with clean before use in each well. The depth-to-water was referenced to the measuring point marked at the top of the innermost well casing.

Sample containers for nitrate analysis were prepared in advance in the laboratories with H_2SO_4 as a preservative. The containers were filled approximately 90-95% full with unfiltered water. pH and EC values of the samples were measured in-situ immediately after collection. During collection, GPS were used for recording the geographical position of each of the sampling spots.

5.4 Sample collection from different sources

Tap water	Un-rusted taps were selected for collection of water samples. These taps were properly cleaned and allowed to flow for a few minutes before collecting the sample.
Tube-well water	The water samples from tube wells were collected after allowing them to flow for at least 10 minutes to get representative sample of the groundwater.
Hand pump/Dug well water	Water samples were collected from hand pumps or dug wells after purging of the hand pump or well.
Stream water/surface water	Water samples were collected from the centre of the stream/other water bodies
Dams, rivers and lakes	It was difficult to obtain a truly representative sample when collecting surface water samples. Sampling point was selected carefully (near to bank in case of river) to avoid any kind of debris in the water.

5.5 Sample containers, filling method, preservation and holding times

Parameter	Volume/ Type	Fill method*	Preservation#	Holding time
Nitrate	250 ml; Polyethylene	Leave head space	H_2SO_4/pH<2 Lab, Cool	28 days
PH and EC	2 x 1 L; Polyethylene	Fill from bottom	Measure at site	2 hours

* Fill container about 90 to 95 % full -do not allow preservative (if present) to be diluted by overfilling container

# Add a predetermined amount of high-purity H_2SO_4 to sample to bring the sample pH down to 2 or less;

Lab = Preservative added to container in laboratory before going into the field,

Cool = Bring temperature down to 4° C and hold at approximately 4° C.

5.6 Analysis of nitrate in water and soil extract

Determination of nitrate is difficult because of the relatively complex procedures required, the high probability of ionic interferences and limited concentration range of various techniques. For uncontaminated water (low in organic matter), UV technique at 220nm is suitable. Besides, nitrate may be determined by ion chromatographic method, nitrate electrode method, Cd reductions method, hydrazine reduction method, etc. The excellent sensitivity, reproducibility, and accuracy of the Griess-Ilosvay method for determining NO_2^- has lead many investigators to develop procedures whereby NO_3 may be reduced to NO_2 and determined by the Griess-Ilosvay technique. The method described for colorimetric analysis of NO_3^- involves the use of a large sized copperized Cd column for reduction of NO_3^- to NO_2^- and detection of NO_2^- formed by the Griess-Ilosvay procedure. This technique was selected because it is relatively simple, not subject to interference by common constituents in soil extracts, and amenable to analysis of 2M KCl extracts of soil.

The colorimetric methods generally employed for determination of NO_2^- are based on the fact that NO_2^- reacts with primary aromatics amines (diazotizing reagents) in acidic solution to produce diazonium salts and that these salts react (couple) with aromatic compounds containing specific amino or hydroxyl groups (coupling reagents) to form colored azo compounds that are suitable for visual or spectrometric measurement. The chief modifications in recent years have been the use of sulfanilamide instead of sulfanilic acid for the diazotization reaction and the use of N- (1-naphthyl)-enthylenediamine instead of 1-naphthyl-amine for the coupling reactions. It has been found that use of these reagents increases the rate of color development, the stability of the color, and the sensitivity of the method

Considering the sample load, sensitivity of methods and level of interferences, automated Cd reductions based colorimetric methods (Flow Injection Analysis) was adopted in this project, and nitrate analysis of water samples from all the target districts was performed at IISS Bhopal with the help of Flow Injection Analyzer (Model: FOSS FIAstar 5000).

6. Results

6.1 Level and extent of nitrate contamination

6.1.1 West Godavari

There was significant variation in NO_3-N load of groundwater samples collected from different blocks (Table 6.1). On average, the NO_3-N load of groundwater of Ganapavaram, Bhimavaram and Poduru was higher than that of others compared (Table 6.1). Although the NO_3-N load in groundwater samples collected from different blocks of the studied district varied significantly, its average load was not more than 10 mg L^{-1}, the threshold limit fixed by WHO for drinking purpose. There was a significant variation in the NO_3-N load of groundwater samples collected from different sources (Table 6.2). In general, with increasing depth of aquifers, the NO_3-N loads of groundwater samples decreased. On an average, the NO_3-N load of groundwater of open well was the highest and that of deep tube well was the lowest. Average depth of sampling of aquifers were as follows: deep-tube well (>150ft) > mini-deep tube well (50-100ft) > shallow-tube well (<50ft) > Hand pump ((<50ft) > Open well (<30ft) (Fig.6.1).The detailed frequency distribution of NO_3-N content of groundwater samples collected from different blocks is presented in Table 6.3. Out of total 1440 samples analyzed, 8% samples were within the range of 0-10 mg L^{-1} and about 20 per cent were above 10 mg L^{-1} range.

Table 6.1: Variation in NO_3-N load of groundwater samples collected from different blocks

Mandal	Range	Mean	SD
High fertilizer consuming blocks			
Nidadavolu	0-70.88	5.63	11.20
Unguturu	0-23.73	4.53	4.63
Tadepalligudem	0-16.09	1.97	3.43
Iragavaram	0-45.16	6.69	9.73
Undi	0-47.21	3.35	6.94
Bhimadolu	0-11.72	2.91	2.38
Bhimavaram	0-70.13	17.56	23.78
Ganapavaram	0-72.91	34.42	15.83
Pentapadu	0-44.90	13.57	11.18
Undrajavaram	0-60.58	10.96	11.25
Penumantra	0-53.06	10.30	13.26
Poduru	0-61.15	14.00	18.55
Palakollu	0-20.10	5.77	6.37
Denduluru	0-6.94	1.83	1.69
Average	0-43.18	9.54	10.02
Medium fertilizer consuming blocks			
Penugonda	0-22.89	3.11	4.75
Atchanta	0-42.61	16.03	12.86
Peravali	0-36.68	14.95	11.56
Tanuku	0-18.11	2.54	4.32
Average	0-30.07	9.16	8.38
Low fertilizer consuming blocks			
Dwarakatuirumala	0-23.30	4.63	3.64
Kalla	0-36.20	7.49	12.29
Average	0-29.75	6.06	7.96
Overall	0-39.22	9.11	9.48

Table 6.2: Overall variations in NO_3-N (mg loading of water samples collec from different sampling sour (West Godavari)

Source (nos)	NO_3-N (mg L^{-1})	
	Range	Mean
Open well(107)	0.02-72.91	11.09
Tube well(214)	0.01-61.15	6.19
Hand pump(145)	0.03-70.8	9.95
Tanks (14)	0.01-62.8	10.18

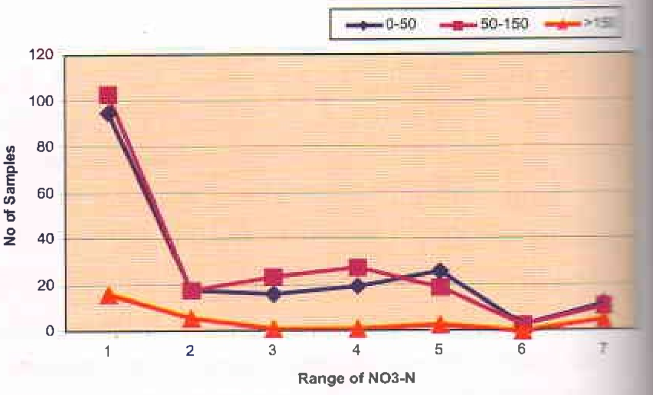


Fig.6.1: Overall variations in NO_3-N (mg L^{-1}) loadi of water samples collected from differe sampling depths (West Godavari)

Table 6.3: Detailed frequency distribution of NO_3-N loading in groundwater samples of the West Godavari district of Andhra Pradesh

MANDAL	No. of Samples	Range					
		ND	0-1	1-3	3-7	7-10	>10
Bhimadolu	90	10(11.1)	11(12.2)	27(30)	39(43.3)	3(3.3)	
Bhimavaram	60	5(5.6)	10(11.1)	6(6.7)	9(10)	9(10)	21(23.3)
Denduluru	60	18(20.0)	696.7)	18(20)	18(20)		
Ganapavaram	30			3(3.3)	2(2.2)	2(2.2)	23(25.6)
Iragavaram	90	10(11.1)	20(22.2)	3(3.3)	15(16.7)	9(10)	33(36.7)
Nidadavolu	60	13.6(13.3)	24(26.7)	12(13.3)		9(10)	3(3.3)
Palakollu	30	5(5.6)	10(11.1)		6(6.7)	3(3.3)	6(6.7)
Pentapadu	60	1(1.1)	5(5.6)	6(6.7)	9(10)	3(3.3)	36(40)
Penumantra	30	2(2.2)	7(7.8)	6(6.7)	3(3.3)		12(13.3)
Poduru	60	9(10)	21(23.3)	3(3.3)	3(3.3)		24(26.7)
Tadepalligudem	120	24(26.7)	30(33.3)	48(53.3)	15(16.7)		3(3.3)
Undi	90	19(21.1)	41(45.6)	6(6.7)	9(10)	6(6.7)	9(10)
Undrajavaram	90	8(8.9)	13(14.4)	15(16.7)	15(16.7)	12(13.3)	27(30)
Unguturu	150	8(8.9)	16(17.8)	60(66.7)	39(43.3)	9(10)	18(20)
Achanta	30			6(6.7)	9(10)	3(3.3)	12(13.3)
Penugonda	60	13(14.4)	20(22.2)	6(6.7)	9(10)	6(6.7)	6(6.7)
Peravali	60	8(8.9)	16(17.8)	6(6.7)			30(33.3)
Tanuku	90	19(21.1)	50(55.6)	3(3.3)	6(6.7)	9(10)	3(3.3)
Dwaraka Tirumala	150	9(10)	15(16.7)	36(40)	69(76.7)	3(3.3)	18(20)
Kalla	30	9(10)	12(13.3)	3(3.3)			6(6.7)
Total	1440	189	327	273	275	86	290
Percentage	100	13.13	22.71	18.96	19.10	5.97	20.14

* Data in parenthesis indicate per cent of total

6.1.2 Ferozepur

First sampling

Nitrate-N concentration of ground waters of Ferozepur district varied from nil to 20 mg L^{-1} with a mean value of 2.59 mg L^{-1} (Table 6.4). In Makhu block, nitrate was absent in all the water samples of different villages. In Ferozepur block highest range (0-20 mg L^{-1}) of nitrate concentration was observed with a mean value of 7.07 mg L^{-1}. Per cent distribution of water samples according to different NO_3-N concentration has been shown in Table 6.5. In the district, 6.2 per cent of the collected water samples contained more than 10 mg L^{-1} NO_3-N. Further NO_3-N was absent in 31.8 per cent water sample and 16.4, 23.4, 12.6, 3.2 and 6.4 per cent samples contained <1, 1-3, 3-5, 5-7 and 7-10 mg L^{-1} NO_3-N, respectively. In Ferozepur and Abohar blocks 22 and 16 per cent water were having NO_3-N concentration more mg L^{-1}.

Table 6.4: Range of NO_3-N and electrical conductivity in water of different blocks of Feroze district

Block	NO_3^--N(mg L^{-1})			EC(dS m^{-1})		
	Range	Mean	S.D.	Range	Mean	S.D.
Mamdot	0 - 3.75	1.35	1.009	0.461-2.794	0.998	0.383
Guru har sahai	0 - 7.82	2.47	1.903	0.408 -1.831	0.912	0.294
Jalalabad	0 -13.88	2.87	3.272	0.749 - 6.974	2.186	1.527
Abohar	0 - 15.04	4.9	4.822	0.404 - 7.580	2.567	1.589
Khuian sarwar	0 - 15.06	4.97	3.094	0.775- 9.680	3.253	2.048
Fazilka	0 - 15.45	4.35	3.939	0.680 - 6.420	2.570	1.404
Ghall khurd	0 - 4.05	1.59	1.157	0.520- 3.614	1.361	0.711
Ferozepur	0 - 20.00	7.07	6.206	0.450 - 3.950	1.458	0.684
Zira	0 - 14.06	3.61	3.114	0.511 -3.227	1.181	0.681
Makhu	Absent	-	-	0.293 -1.189	0.619	0.238
Overall	0 - 20.00	2.59	-	0.404 - 9.680	1.710	-

Table 6.5: Per cent distribution of water samples according to different NO_3-N concentrations

Block	NO_3^--N(mg L^{-1})						
	ND	<1	1-3	3-5	5-7	7-10	>10
Mamdot	34	34	28	4	-	-	-
Guru har sahai	38	18	24	14	4	2	-
Jalalabad	34	22	20	16	-	4	4
Abohar	14	22	24	8	6	10	16
Khuian sarwar	6	4	26	32	2	24	6
Fazilka	8	16	32	14	12	8	10
Ghall khurd	34	26	30	10	-	-	-
Ferozepur	34	8	16	12	2	6	22
Makhu	100	-	-	-	-	-	-
Zira	16	14	34	16	6	10	4
Overall	31.8	16.4	23.4	12.6	3.2	6.4	6.2

Second sampling

Nitrate-N concentration of ground waters of Ferozepur district during 2nd sampling is shown in Table 6.6. It varied from nil to 48.2 mg L^{-1} with a mean value of 3.5 mg L^{-1}. In Makhu block nitrate concentration of different selected villages again varied from nil to 0.25 mg L^{-1} with a mean value of 0.02 mg L^{-1}. During 1st sampling nitrate was absent in all the water samples collected. So during second sampling, five different villages were selected and water samples were collected from these villages. Thus it is quite evident from the survey that nitrate was almost absent or in very negligible amounts of the sampled areas. Per cent distribution of water samples according to different NO$_3$--N concentrations is shown in Table 6.7.

It is evident from the data that 9.6 per cent water samples contained NO$_3$-N more than 10 mg L^{-1} as compared to 6.2 per cent during previous sampling. NO$_3$-N was not detectable in 31.3 per cent water samples. During repeat sampling 10.4, 22.1, 18.3, 5.4 and 2.9 per cent water samples contained NO$_3^-$-N <1, 1-3, 3-5, 5-7 and 7-10 mg L^{-1} respectively in this district as a whole. In Fazilka block during repeat sampling 21.7 percent water samples contained NO$_3$-N more than 10 mg L^{-1} as compared to 10 per cent during 1st sampling.

Table 6.6: Range of NO$_3$-N and electrical conductivity in water of different blocks

Block	NO$_3$ - N(mg L^{-1})			EC(dS m^{-1})		
	Range	**Mean**	**S.D.**	**Range**	**Mean**	**S.D.**
Guru har sahai	0.0 - 7.45	2.06	1.754	0.403-1.990	1.049	0.308
Jalalabad	0.0-7.40	2.15	2.476	0.725-10.09	3.064	3.380
Abohar	0.0-16.90	7.7	6.712	0.634-5.236	2.831	1.619
Khuian sarwar	0.0-7.65	2.66	2.741	0.881-8.600	2.912	2.643
Fazilka	0.0-48.20	6.7	9.77	0.619-6.700	2.346	1.419
Makhu	0.0-0.25	0.02	0.057	0.302-1.196	0.670	0.237
Zira	0.0-15.60	3.74	3.53	0.573-5.891	1.283	0.937
Overall	0.0-48.2	3.5	5.62	0.302-10.09	1.642	1.574

Table 6.7: Per cent distribution of water samples according to different NO$_3$-N concentrations

Block	NO$_3^-$-N(mg L^{-1})						
	ND	**<1**	**1-3**	**3-5**	**5-7**	**7-10**	**>10**
Guru har sahai	20	16	38	22	2	2	-
Jalalabad	44.4	5.5	5.6	33.3	5.6	5.6	-
Abohar	10.5	15.8	15.8	-	5.3	5.3	47.3
Khuian sarwar	14.3	28.6	14.3	28.6	-	14.2	-
Fazilka	2.2	4.3	37.0	26.1	8.7	-	21.7
Makhu	90	10	-	-	-	-	-
Zira	16	8	24	26	12	6	8
Overall	31.3	10.4	22.1	18.3	5.4	2.9	9.6

Third sampling

Nitrate-N concentration of ground waters of Ferozepur district during 3rd sampling is shown in Table 6.8. It varied from nil to 42.97 mg L^{-1} with a mean value of 4.62 mg L^{-1}. In Makhu block nitrate concentration of different selected villages varied from nil to 2.87 mg L^{-1} with a mean value of 1.09 mg L^{-1}. During 1st sampling nitrate was absent in all the water samples collected. So during second sampling, five different villages were selected and water samples were collected from these villages and their concentrations varied from nil to 0.25 mg L^{-1} with a mean value of 0.02 mg L^{-1}. Thus it is qui evident from the survey that nitrate concentrati was very less in the sampled areas. Per ce distribution of water samples according to differe NO_3-N concentration is shown in Table 6.9.

Table 6.8: Range of NO_3-N and electrical conductivity in water of different blocks of Ferozepur

Block	NO_3^--N(mg L^{-1})			EC(dS m^{-1})		
	Range	Mean	S.D.	Range	Mean	S.D.
Mamdot	0- 2.96	0.58	0.89	0.545-2.772	1.132	0.381
Guru har sahai	0- 28.95	4.24	6.93	0.412-2.616	1.460	0.568
Jalalabad	0- 34.1	4.70	7.19	0.905-7.372	2.139	1.117
Abohar	0- 10.35	2.96	2.54	1.407-9.592	3.849	1.939
Khuian sarwar	0- 42.97	8.9	10.54	0.414-9.718	3.703	2.647
Fazilka	0 - 39.69	9.37	9.51	0.901-5.815	2.641	1.107
Ghall khurd	0 - 25.37	4.14	6.19	0.695-5.939	1.981	1.659
Ferozepur	0- 40.01	8.77	11.28	0.875-2.315	1.456	0.470
Makhu	0- 2.87	1.09	1.33	0.649-7.125	0.983	0.904
Zira	0 - 14.44	3.5	2.61	0.716-3.325	1.433	0.681
Overall	0 - 42.97	4.62	7.51	0.412-9.718	1.949	1.560

Table 6.9: Per cent distribution of water samples according to different NO_3^- - N concentrations

Block	NO_3^--N(mg L^{-1})						
	ND	<1	1-3	3-5	5-7	7-10	>10
Mamdot	56	16	28	-	-	-	-
Guru har sahai	50	18	4	4	4	-	20
Jalalabad	27.5	10	22.5	17.5	15.0	-	7.5
Abohar	20	13	19	42	-	3	3
Khuian sarwar	7	12	21	11	7	19	23
Fazilka	10	12	18	10	4	4	42
Ghall khurd	37	8	27	8	4	4	12
Ferozepur	31	2	20	14	2	-	31
Makhu	60	-	40	-	-	-	-
Zira	10	10	28	36	8	6	2
Overall	31.5	10.0	23.0	13.2	4.3	3.5	14.5

It was evident from the data that 14.5 per cent water samples contained NO_3-N more than 10 mg L^{-1} as compared to 9.6 and 6.2 per cent during 2nd and 1st sampling. During third repeat sampling NO_3-N was absent in 31.5 per cent water samples. Further <10, 23, 13.2, 4.3, 3.5 and 14.5 per cent water samples contained <1, 1-3, 3-5, 5-7, 7-10 and >10 mg L^{-1} NO_3N concentration. In Fazilka block during repeat sampling 42 percent water samples contained NO_3-N more than 10 mg L^{-1} as compared to 21.7 and 10 per cent during 2nd and 1st sampling, respectively.

6.1.3 Hooghly

There was significant variation in NO_3-N load of groundwater samples collected from different blocks (Table 6.10). On average, the NO_3-N load of groundwater of Arambag, Dhaniakhali and Polba blocks was higher than that of others compared (Table 6.10). Although the NO_3-N load in groundwater samples collected from different blocks of the studied district varied significantly, its load was well below the 10 mg L^{-1}, the threshold limit fixed by WHO for drinking purposes. There was always a significant variation in the NO_3-N load of groundwater samples collected from different sources (Table 6.11). In general, with increasing depth of aquifers, the NO_3-N loads of groundwater samples decreased. On average, the NO_3-N load of groundwater of well was the highest and that of deep tube well was the lowest. Average depths of sampling aquifers were as follows: deep-

Table 6.10: Variation in NO_3-N load of groundwater samples collected from different blocks of the Hooghly district of West Bengal

Blocks	NO_3-N loading in groundwater (mg L^{-1})		
	Range	Mean	SD
Mogra	0.12-2.01	0.60	0.31
Balagar	0.16-2.44	0.79	0.45
Pandua	0.06-3.58	0.73	0.55
Polba	0.12-6.42	0.89	0.84
Chanditala-I	0.13-2.36	0.64	0.39
Chanditala-II	0.12-4.11	0.80	0.68
Singur	0.07-4.13	0.74	0.67
Haripal	0.12-3.18	0.83	0.55
Goghat-I	0.02-2.56	0.61	0.53
Goghat-II	0.05-4.03	0.81	0.82
Khanakul-I	0.06-4.23	0.63	0.71
Khanakul-II	0.16-4.11	0.71	0.63
Arambag	0.01-6.41	0.94	0.99
Tarakeswar	0.04-2.34	0.63	0.42
Pursura	0.17-4.01	0.70	0.57
Dhaniakhali	0.04-6.11	0.83	0.91
Jangipara	0.02-3.58	0.61	0.56
Overall	0.01-6.42	0.76	0.67

Table 6.11: Overall variations in NO_3-N (mg L^{-1}) loading of water samples collected from different sampling aquifer depths

Source (nos)	Depth (m)			NO_3-N (mg L^{-1})		
	Range	Mean	SD	Range	Mean	SD
Well (8)	18.3-30.5	23.62	4.23	0.54-2.16	1.43	0.50
TW (470)	24.4-106.7	46.24	9.79	0.04-6.42	1.04	0.74
STW (258)	36.6-85.3	58.57	8.49	0.02-4.25	0.45	0.35
MDTW (57)	42.7-106.7	67.70	11.87	0.06-0.88	0.37	0.14
DTW (75)	91.4-152.4	113.93	12.04	0.01-0.77	0.24	0.11

tube well (113.m) > mini-deep tube well (67.7 m) > shallow-tube well (58.6 m) > tube-well (46.2 m) > open well (23.6 m). The detailed frequency distribution of NO_3-N loading of groundwater samples collected from different blocks is presented in Table 6.12. From the Table it w evident that out of total 2604 samples analyz 81.1% samples were within the range of 0-1 mg L and only 1.9% was within 3-7 mg L^{-1} range with maximum value of 6.42 mg L^{-1}.

Table 6.12: Detailed frequency distribution of NO_3-N loading in groundwater samples of th Hooghly district of West Bengal

Blocks	Number (per cent) of samples having NO_3-N loading (mg L^{-1})						
	ND	0-1.0	1.0-3.0	3.0-7.0	7.0-10.0	>10.0	Total
Mogra	0	81 (93.1)	6 (6.9)	0	0	0	87 (100)
Balagar	0	184 (78.6)	50 (21.4)	0	0	0	234 (100)
Pandua	0	179 (85.2)	28 (13.3)	3 (1.4)	0	0	210 (100)
Polba	0	158 (76.3)	42 (20.3)	7 (3.4)	0	0	207 (100)
Chanditala-I	0	122 (92.4)	10 (7.6)	0	0	0	132 (100)
Chanditala-II	0	97 (77.0)	26 (20.6)	3 (2.4)	0	0	126 (100)
Singur	0	115 (79.9)	26 (18.1)	3 (2.1)	0	0	144 (100)
Haripal	0	154 (76.6)	46 (22.9)	1 (0.5)	0	0	201 (100)
Goghat-I	0	118 (83.7)	23 (16.3)	0	0	0	141 (100)
Goghat-II	0	123 (75.9)	32 (19.8)	7 (4.3)	0	0	162 (100)
Khanakul-I	0	91 (91.9)	6 (6.1)	2 (2.0)	0	0	99 (100)
Khanakul-II	0	85 (85.9)	11 (11.1)	3 (3.0)	0	0	99 (100)
Arambag	0	151 (68.9)	59 (26.9)	9 (4.1)	0	0	219 (100)
Tarakeswar	0	128 (85.3)	22 (14.7)	0	0	0	150 (100)
Pursura	0	108 (85.7)	17 (13.5)	1 (0.8)	0	0	126 (100)
Dhaniakhali	0	123 (77.4)	27 (17.0)	9 (5.7)	0	0	159 (100)
Jangipara	0	95 (88.0)	11 (10.2)	2 (1.9)	0	0	108 (100)
Overall	0	2112 (81.1)	442 (17.0)	50 (1.9)	0	0	2604 (100)

6.1.4 Jalgaon

The NO_3-N load of groundwater samples collected from different blocks (Table 6.13) was not detected in the pre-monsoon 2006. But during pre and post-monsoon of 2007 the nitrate was detected in only in three samples in each season. During pre monsoon 2007 season nitrate was detected in Chalisgaon, Raver and Muktai nagar and during post monsoon 2007 season nitrate was detected in Jalgaon, Bhadgaon and Dharangaon blocks only. By and large no nitrate load was found in the Jalgaon district. In general, the nitrate was not detected in the water samples during all the three seasons but only in six samples it was detected (Table 6.14). However, out of six samples, two samples recorded No_3-N more than 10 mg L^{-1} (WHO limit) whereas three samples were within 3-7 mg L^{-1} and only one sample was between 1-3 mg L^{-1}.

Table 6.13: Nitrate loadings in water (mg L^{-1}) in different blocks of the Jalgaon district of Maharashtra.

Block	Range	Mean	No of samples
Bhadgaon	0-16.78		160
Raver	0-4.85		147
M'Nagar	0-6.08		161
Yaval	0	0	133
Jalgaon	0-18.93		149
Bodwad	0	0	69
Chopada	0	0	77
Erandol	0	0	87
Bhusawal	0	0	91
Dharangaon	0-1.84		91
Pachora	0	0	30
Parola	0	0	29
40'Gaon	0-6.82		28
Amalner	0	0	23
Jamner	0	0	30
Grand Total	0-18.93		1306

Table 6.14: Frequency distribution of nitrate(mg L^{-1})contamination in different blocks of water samples in Jalgaon district (3-samplings)

Block	ND	0--1	1--3	3--7	7--10	> 10	Total
High FU							
Bhadgaon	159	0	0	0	0	1	160
Raver	147	0	0	1	0	0	148
M'Nagar	160	0	0	1	0	0	161
Yaval	133	0	0	0	0	0	133
Jalgaon	148	0	0	0	0	1	149
Medium FU							
Bodwad	69	0	0	0	0	0	69
Chopada	77	0	0	0	0	0	77
Erandol	87	0	0	0	0	0	87
Bhusawal	91	0	0	0	0	0	91
Dharangaon	90	0	1	0	0	0	91
Low FU							
Pachora	30	0	0	0	0	0	30
Parola	29	0	0	0	0	0	29
40'Gaon	27	0	0	1	0	0	28
Amalner	23	0	0	0	0	0	23
Jamner	30	0	0	0	0	0	30
Grand Total	1300	0	1	3	0	2	1306

6.1.5 Coimbatore

The mean NO_3-N content of groundwater samples of different blocks varied from 5.20 to 9.52 mg L^{-1} with the overall mean value of 6.74 mg L^{-1} (Table 6.15). Significant variation in NO_3-N content of groundwater samples collected from different blocks was observed while comparing the mean values of the NO_3-N content, groundwater samples collected from Gudimangalam, Periyanaickenpalayam and Sultanpet blocks recorded higher values compared to other blo studied. Although the NO_3-N content groundwater samples collected from diffe blocks of the selected district varied significa its content was well below the critical level of mg L^{-1}.

The variations in the NO_3-N content groundwater samples collected from diffe sources are given in Table 6.16. The mean aqui depth ranged from 28.7 to 352.0 feet, while

Table6.15: Variation in NO_3-N load of groundwater samples collected from different blocks of Coimbatore district of Tamil Nadu

Blocks	Nitrate-N loading in groundwater (mg L^{-1})		
	Range	Mean	SD
	Low intensity		
Pongalur	0.7 - 15.15	6.10	3.37
Annur	0.0 - 14.16	5.43	3.81
Avinashi	0.0 - 13.36	5.89	3.71
Sarcarsamakulam	0.0 - 17.18	6.66	4.21
Sulur	0.0 - 13.2	5.20	3.56
	Medium Intensity		
Periyanaickenpalayam	0.0 - 36.23	8.24	8.26
Karamadai	0.0 - 19.66	7.11	4.58
Kinathukadavu	0.02 - 24.23	6.91	6.01
Madukarai	0.0 - 25.60	7.17	6.78
Sultanpet	0.0 - 35.82	8.01	7.63
Udumalpet	0.0 - 40.04	7.72	9.05
	High Intensity		
Perur	0.0 - 30.88	7.16	6.91
Thondamuthur	0.0 - 28.42	5.82	6.30
Anamalai	0.0 - 31.95	5.26	6.17
Pollachi-North	0.0 - 44.30	7.05	9.03
Pollachi-South	0.0 - 36.32	5.68	5.78
Gudimangalam	0.0 - 45.76	9.52	8.47
Madathukulam	0.0 - 28.08	6.03	6.86
Overall	0.0 - 45.76	6.74	6.79

Table 6.16: Overall variations in NO_3-N (mg L^{-1}) loading of water samples collected from different sampling aquifer depths

Sources (Numbers)	Depth (Feet)			Nitrate-N (mg L^{-1})		
	Range	Mean	SD	Range	Mean	SD
Open well (504)	30 - 200	77.63	29.39	0.00 - 37.95	6.53	6.42
Bore well (433)	120 - 800	352.03	108.63	0.00 - 37.40	6.16	6.25
Hand pump (136)	15 - 50	28.71	9.31	0.00 - 45.76	9.34	8.92

highest was in bore well and the lowest in hand pump. The NO_3-N content was highest in the hand pump followed by open well and the lowest in bore well. Hence it is inferred that with increase in aquifers depth there was a decrease in NO_3-N content of ground water.

Table 6.17: Detailed frequency distribution of NO_3-N loading in groundwater samples of the Coimbatore district of Tamil Nadu

Blocks	Number (per cent) of samples having Nitrate-N loading (mg L^{-1})						
	ND	0-1	1-3	3-7	7-10	> 10	Total
Low intensity							
Pongalur	0 (0.0)	1 (3.3)	4(13.3)	15 (50.0)	7 (23.3)	3 (10.0)	30 (100)
Annur	2 (5.9)	4 (11.8)	3 (8.8)	14 (41.2)	8 (23.5)	3 (8.8)	34 (100)
Avinashi	2 (7.1)	1 (3.6)	4 (14.3)	11 (39.3)	7 (25.0)	3 (10.7)	28 (100)
Sarcarsamakulam	2 (5.9)	0 (0.0)	6 (17.6)	12 (35.3)	9 (26.5)	5 (14.7)	34 (100)
Sulur	2 (7.1)	2 (7.1)	5 (17.9)	9 (32.1)	8 (28.6)	2 (7.1)	28 (100)
Medium Intensity							
Periyanaickenpalayam	2 (3.8)	3 (5.7)	7 (13.2)	20 (37.7)	10 (18.9)	11 (20.8)	53 (100)
Karamadai	3 (5.8)	0 (0.0)	6 (11.5)	18 (34.6)	14 (26.9)	11 (21.2)	52 (100)
Kinathukadavu	1 (1.9)	2 (3.8)	14 (26.9)	16 (30.8)	10 (19.2)	9 (17.3)	52 (100)
Madukarai	4 (8.5)	1 (2.1)	9 (19.1)	15 (31.9)	10 (21.3)	8 (17.0)	47 (100)
Sultanpet	2 (4.9)	2 (4.9)	6 (14.6)	12 (29.3)	11 (26.8)	8 (19.5)	41 (100)
Udumalpet	4 (8.5)	8 (17.0)	3 (6.4)	13 (27.7)	11 (23.4)	8 (17.0)	47 (100)
High Intensity							
Perur	8 (7.0)	13 (11.4)	20 (17.5)	32 (28.1)	10 (8.8)	31 (27.2)	114 (100)
Thondamuthur	10 (9.3)	18 (16.8)	24 (22.4)	20 (18.7)	12 (11.2)	23 (21.5)	107 (100)
Anamalai	12 (15.2)	9 (11.4)	17 (21.5)	20 (25.3)	6 (7.6)	15 (19.0)	79 (100)
Pollachi-North	11 (12.8)	13 (15.1)	12 (14.0)	25 (29.1)	4 (4.7)	21 (24.4)	86 (100)
Pollachi-South	11 (13.1)	7 (8.3)	21 (25.0)	14 (16.7)	13 (15.5)	18 (21.4)	84 (100)
Gudimangalam	7 (9.9)	2 (2.8)	5 (7.0)	13 (18.3)	24 (33.8)	20 (28.2)	71 (100)
Madathukulam	14 (16.3)	9 (10.5)	18 (20.9)	17 (19.8)	7 (8.1)	21 (24.4)	86 (100)
Overall	97 (9.04)	95 (8.85)	184 (17.2)	296 (27.6)	181 (16.9)	220 (20.5)	1073 (100)

The frequency distribution of NO_3-N content of groundwater samples collected from different blocks is depicted in Table 6.17. The results indicated that out of total 1073 samples analyzed 9.04 per cent samples has not recorded NO_3-N and 8.85, 17.2, 27.6 and 16.9 per cent samples were with in the range of 0-1, 1-3, 3-7 and 7-10 mg L^{-1}, whereas 20.5 per cent samples recorded NO_3-N above the critical level of 10 mg L^{-1}.

6.1.6 Hoshangabad district

Extent of Nitrate Contamination in Groundwater

Frequency distribution of level of nitrate contamination in water samples collected from different block during pre-monsoon 2006, and pre- and post-monsoon of 2007 is given in Table 6.18. As a whole, 7.7 per cent samples were polluted with nitrate, whereas 7.0 per cent samples did not contain any nitrate. Majority of samples was in the range of 1-7 mg L^{-1} NO_3-N (72.0%), while 5.8 per cent samples contained 7-10 mg L^{-1} nitrate-N and were most vulnerable. Among the blocks, Seoni Malwa recorded the highest proportion of polluted samples, while Bankhedi recorded the lowest. Extent of nitrate pollution did not differ significantly across seasons, 8.2 per cent being in pre-monsoon 2006, and 7.7 and 7.2 per cent respectively, in pre- and post-monsoon 2007 (Table 6.19).

Table 6.18: Block wise frequency distribution of NO_3-N loading of groundwater samples

Block	ND	0-1	1-3	3-7	7-10	>10
Seoni-malwa	26 (8.8)*	20 (6.8)	57 (19.5)	121 (41.2)	23 (7.8)	46 (15.6)
Babai	3 (1.1)	4 (1.5)	96 (35.0)	145 (54.1)	5 (1.8)	15 (5.6)
Hoshangabad	19 (6.2)	17 (5.6)	93 (30.7)	130 (42.9)	27 (8.9)	17 (5.6)
Piparia	22 (8.9)	22 (8.9)	92 (37.2)	72 (29.1)	13 (5.2)	26 (10.5)
Kesla	22 10.7)	35 (17.0)	49 (29.1)	80 (39.0)	9 (4.4)	10 (4.8)
Bankhedi	4 (3.0)	16 (12.0)	64 (47.7)	44 (32.8)	5 (3.7)	1 (0.7)
Sohagpur	10 14.4)	--	25 (36.3)	26 (37.7)	6 (8.7)	2 (2.8)
Total	106(7.0)	114 (7.5)	476 (31.3)	618 (40.7)	88 (5.8)	117 (7.7)

* Data in parenthesis are the percentage figures

Table 6.19: Season wise frequency distribution of NO_3-N loading of groundwater samples

Season	ND	0-1	1-3	3-7	7-10	>10	Total
Pre-monsoon 2006	22 (4.6)	26 (5.5)	174 (36.8)	182 (38.2)	32 (6.7)	39 (8.2)	475
Pre-monsoon 2007	42 (8.04)	48 (9.2)	152 (29.1)	212 (40.6)	28 (5.4)	40 (7.7)	522
Post-monsoon 2007	42 (8.04)	40 (7.6)	150 (28.7)	224 (42.9)	28 (5.4)	38 (7.2)	522
Total	106 (7.0)	114 (7.5)	476 (31.3)	618 (40.7)	88 (5.7)	117 (7.7)	1519

* Data in parenthesis are the percentage figures

Extent of nitrate pollution in different sources of water is presented in Table 6.20. Among the sources, hand pumps were more polluted with nitrate than open wells and tube wells. While10 per cent hand pumps were polluted with nitrate, the figures for open wells and tube wells were 9 and 4 per cent, respectively. When the data were stratified with respect to fertilizer usage, more polluted samples were found in high fertilizer usage areas as compared to medium and low areas. Frequency distribution of level of nitrate contamination in water samples from different locations is given in Table 6.21. As a whole, the sources from habitation areas are much more polluted (17.8%) than those from field (5.5%) and dairy areas.

Table 6.20: Frequency distribution of nitrate contamination (mg N L^{-1}) in different sources of water

Sources	ND	0-1	1-3	3-7	7-10	>10
Open well	69 (8.0)	66 (7.5)	225 (25.7)	380 (43.5)	55 (6.3)	79 (9.0)
Tube well	25 (5.8)	35 (8.1)	172 (40.1)	159 (37.0)	21 (5.0)	17 (4.0)
Hand pump	11 (5.2)	13 (6.2)	75 (35.5)	79 (37.4)	12 (5.7)	21 (10.0)
Total	105 (7.0)	114 (7.5)	472 (31.2)	618 (40.8)	88 (5.8)	117 (7.7)

* Data in parenthesis are the percentage figures

Table 6.21: Frequency distribution of nitrate contamination (mg N L^{-1}) in different locations of water

Location	ND	0-1	1-3	3-7	7-10	>10
Field	86 (7.1)	102 (8.4)	375 (31.0)	514 (42.5)	65 (5.4)	67 (5.5)
Habitation	19 (6.8)	8 (2.8)	92 (32.8)	91 (32.5)	20 (7.1)	50 (17.8)
Dairy	-	4 (16.0)	5 (20.0)	13 (52.0)	3 (12.0)	-
Total	105 (7.0)	114 (7.5)	472 (31.2)	618 (40.8)	88 (5.8)	117 (7.7)

* Data in parenthesis are the percentage figures

Source x location matrix on frequency distribution of extent of nitrate contamination (Table 6.22) suggests that all sources of water in proximity to habitation areas were significantly more polluted than those in proximity to field and dairy areas. As high as 29.5 per cent open wells in proximity to the habitation areas were polluted with nitrate, whereas only 6.9 per cent open wells near field areas were polluted. Similarly, tube wells in proximity to habitation areas were more polluted than those in dairy and crop fields. While 16.3 per cent tube wells in habitation areas were polluted, only 2.1 per cent tube wells from field areas were polluted. The extent of nitrate pollution in hand pumps, which were mostly confined in habitation areas, was quite high to the extant of 14 per cent of hand pumps investigated.

Table 6.22: Source x location matrix of the extent of nitrate pollution in groundwater

Location/Source	Field	Habitation	Dairy	Total
Open well	57 (6.9)	22 (29.5)	0	79 (9.0)
Tube well	10 (2.1)	7 (16.3)	0	17 (4.0)
Hand pump	0	21 (14.0)	0	20 (10.0)
Total	67 (5.5)	50 (17.8)	0	117 (7.7)

* Data in parenthesis are the percentage figures

Level of nitrate contamination in Groundwater

The mean NO_3-N content of groundwater samples of different blocks collected during pre-monsoon 2006, pre- and post-monsoon 2007 varied from 2.99 to 6.32 mg N L^{-1}, Bankheri recording the lowest and Seoni Malwa the highest, with the overall mean value of 4.55 mg N L^{-1} (Table 6.23). Significant variation in NO_3-N content of groundwater samples as per fertilizer usage in different blocks was observed while comparing the mean values of the NO_3-N content of groundwater samples. High fertilized areas had a higher nitrate level in ground waters (5.28 mg N L^{-1}) as compared to medium (3.79 mg N L^{-1}) and low fertilized areas (3.17 mg N L^{-1}). Although the mean nitrate values of all the blocks were well below the critical limits of WHO standards for drinking water, there were quite a significant number of wells which recorded nitrate pollution signifying high variability in nitrate values in ground waters. Very high SD values are indicative of this.

Table 6.23: Variation in NO_3-N load of groundwater samples collected from different blocks

Intensity of fertilizer usage	Block	Number of sample	Range	Mean (mg N L^{-1})	SD	Mean (mg N L^{-1}) as per fertilizer usage
High	Seoni-malwa	293	0-61.45	6.32	8.50	5.28
	Babai	268	0-88.92	4.98	8.22	
	Hoshangabad	303	0-86.55	4.54	6.81	
Medium	Piparia	247	0-37.40	3.98	4.51	3.79
	Kesla	205	0-43.98	3.57	4.86	
Low	Bankhedi	134	0-13.77	2.99	2.21	3.17
	Sohagpur	69	0-10.63	3.51	2.69	
Total		1519	0-88.92	4.55	-	-

NO_3-N loading in different sources of water collected during three seasons of 2006 and 2007 from different blocks is presented in Table 6.24. Overall, the highest mean nitrate concentration was recorded in hand pumps (4.4 mg N L^{-1}) followed by open wells (4.3mg N L^{-1}) and tube wells (3.8mg N L^{-1}). The highest level of nitrate in open wells, tube wells and hand pumps were 88.9, 43.9 and 25.1 mg N L^{-1}, respectively. It is also evident that the highest fertilizer usage areas recorded significantly higher NO_3-N as compared to low and medium fertilizer usage areas. Overall highest level of nitrate contamination was found ground waters near habitation areas (5.5 mg N L (Table 6.25). As a whole the mean NO concentration in ground waters collected from field and dairy areas was 3.8 mg L^{-1} (Table 6.2 Source x location matrix table (Table 6.26) clea suggested that habitation samples w significantly more contaminated with nitrate field samples and samples from the vicinity dairy/poultry. The mean nitrate levels in all sou of water near habitation were higher, 11.1, 6.2 4.7 mg N L^{-1} being recorded in open wells. wells and hand pumps, respectively, as against and 3.1 mg N L^{-1} in field areas and 4.5, 4.3 and mg N L^{-1} in dairy/poultry (Table 6.26).

6.2 Temporal variation in nitrate contamination in the representative aquifers

6.2.1 West Godavari

Variations in pH of groundwater

There was significant variation in pH of groundwater samples collected from different mandals in three different seasons (Fig. 6.2). On average, the pH of groundwater of Penumantra, Poduru and Undi mandals was higher than that of others compared. Results indicated that the groundwater of different mandals of West Godavari is almost neutral to slightly alkaline in reaction.In general, pH values of groundwater samples collected during post-monsoon season of 2006 was comparatively less than pre-monsoon seasons of both the year (2006 and 2007).

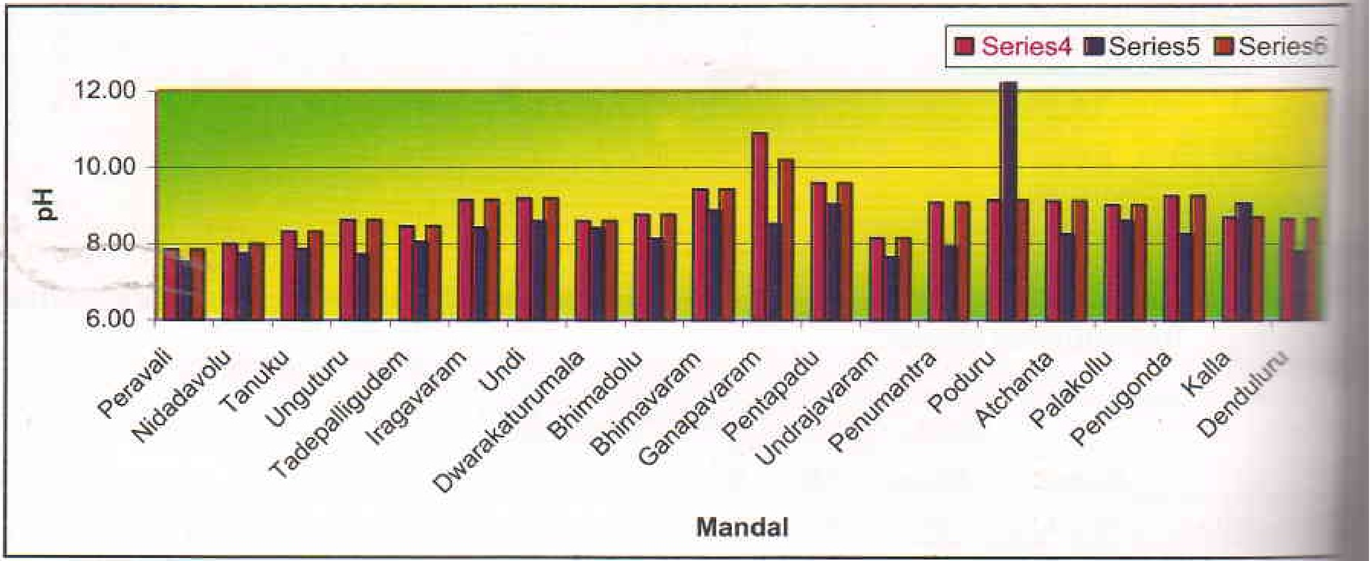


Fig. 6.2: Season-wise and block-wise variation in pH values of groundwater (Series4 = pre-monsoon 2006, Series5 = post-monsoon seasons 2006 and Series6= pre-monsoon season 2007)

Variations in EC values of groundwater

There was significant variation in EC values of groundwater samples collected from different mandals in three different seasons (Fig. 6.3). On average, the EC values of groundwater of Undi, Kalla and Pentapadu blocks were higher than that other mandals compared.However, results indicated that the EC values of groundwater of different mandals of West Godavari was within the normal range of electrical conductivity (< 2.dSm^{-1}), and would cause no adverse effect on plant growth and also if use for drinking purposes, so far salinity in concerned. Although the variation was minor, it was observed that there was always a higher value of EC of groundwater samples collected during pre-monsoon seasons of 20 2007 than that of samples collected during monsoon season of 2006.

Variations in NO_3-N load of groundwater

There was significant variation in load of groundwater samples collected different mandals in three different seasons 6.4 and 6.5). On average, the NO_3-N groundwater of Ganapavaram, Bhimav Poduru was higher than that of others compared during both the seasons (Fig Although the NO_3-N load in groundwater collected from different mandals of the district varied significantly, in 80 per cent samples was well below the 10 mg L^{-1}, the threshold limit fixed by WHO for drinking purpose. There was always a significant variation in the NO_3-N load of groundwater samples collected from different sources in different seasons. In general, with increasing depth of sampling aquifers, the NO_3-N loads of groundwater samples decreased. This was true for both the years (2006 and 2007) and seasons (pre and post-monsoon) of sampling.

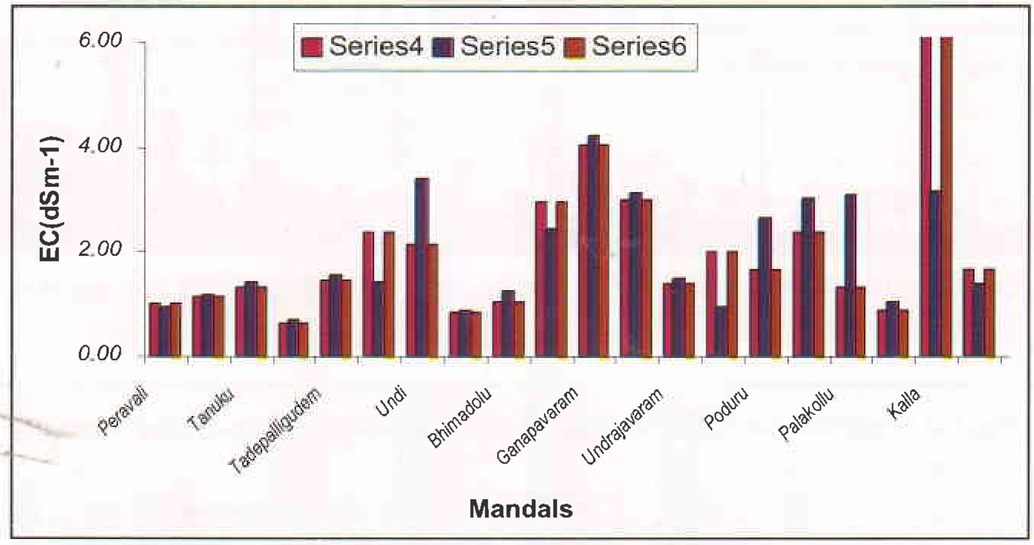


Fig. 6.3: Season-wise and block-wise variation in EC(dSm^{-1}) values of groundwater (Series4= pre-monsoon season 2006, Series5= post-monsoon seasons 2006 and Series6= pre-monsoon season 2007)

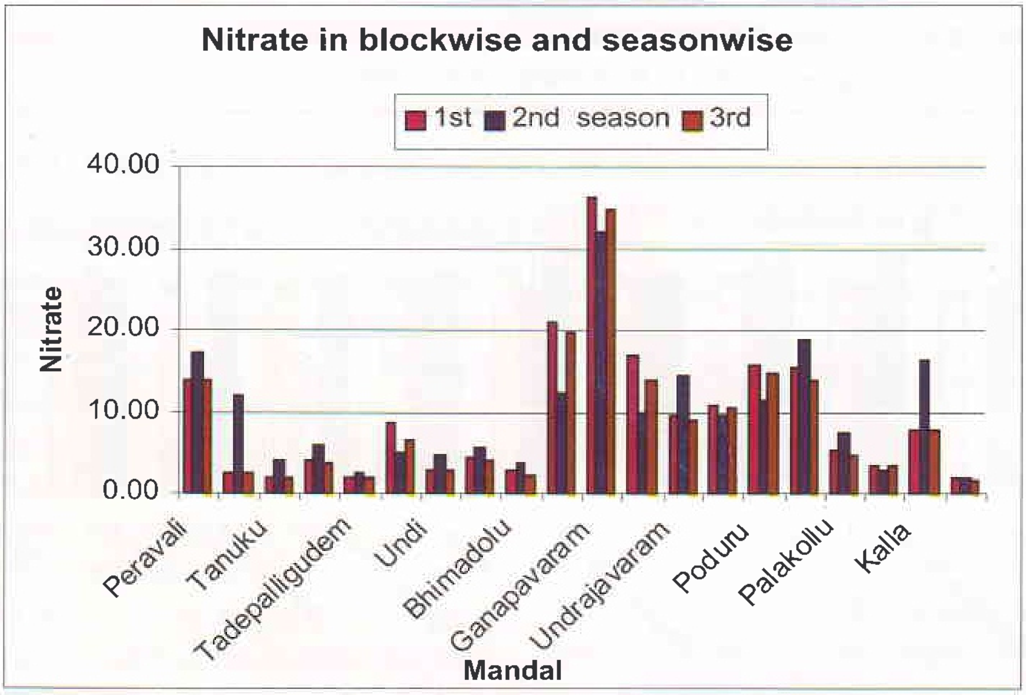


Fig. 6.4: Season-wise and block-wise variation in NO_3-N (mg l^{-1}) loading in groundwater (1st season = pre-monsoon season 2006, 2nd season = post-monsoon seasons 2006 and 3rd season= pre-monsoon season 2007)

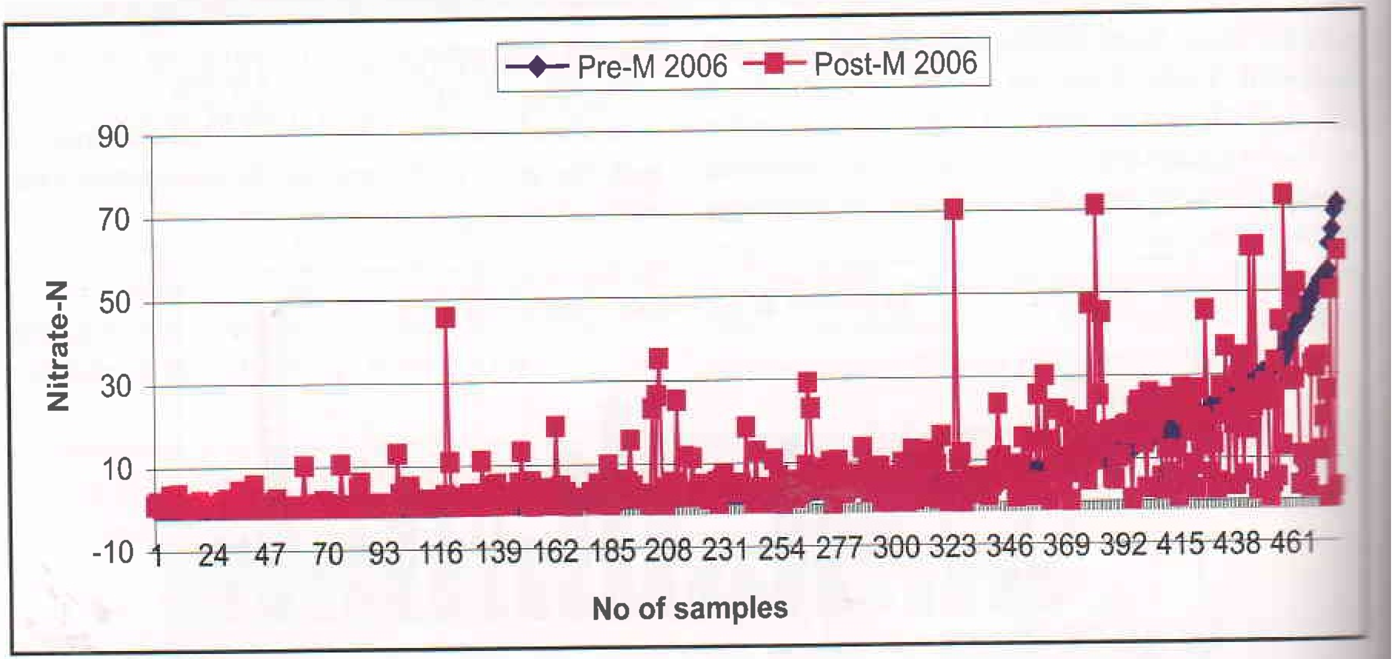


Fig. 6.5 Temporal variations of NO_3-N (mg l^{-1}) loading in groundwater samples

6.2.2 Ferozepur

Variations in pH of groundwater

There was no significant variation in pH of groundwater samples collected from different blocks of Ferozepur in three different seasons (Fig. 6.6). On an average, the pH of groundwater of Guruhar Sahai block was higher than those of others. Results indicated that the ground waters of different blocks of Ferozepur were almost neutral to slightly alkaline in reaction.

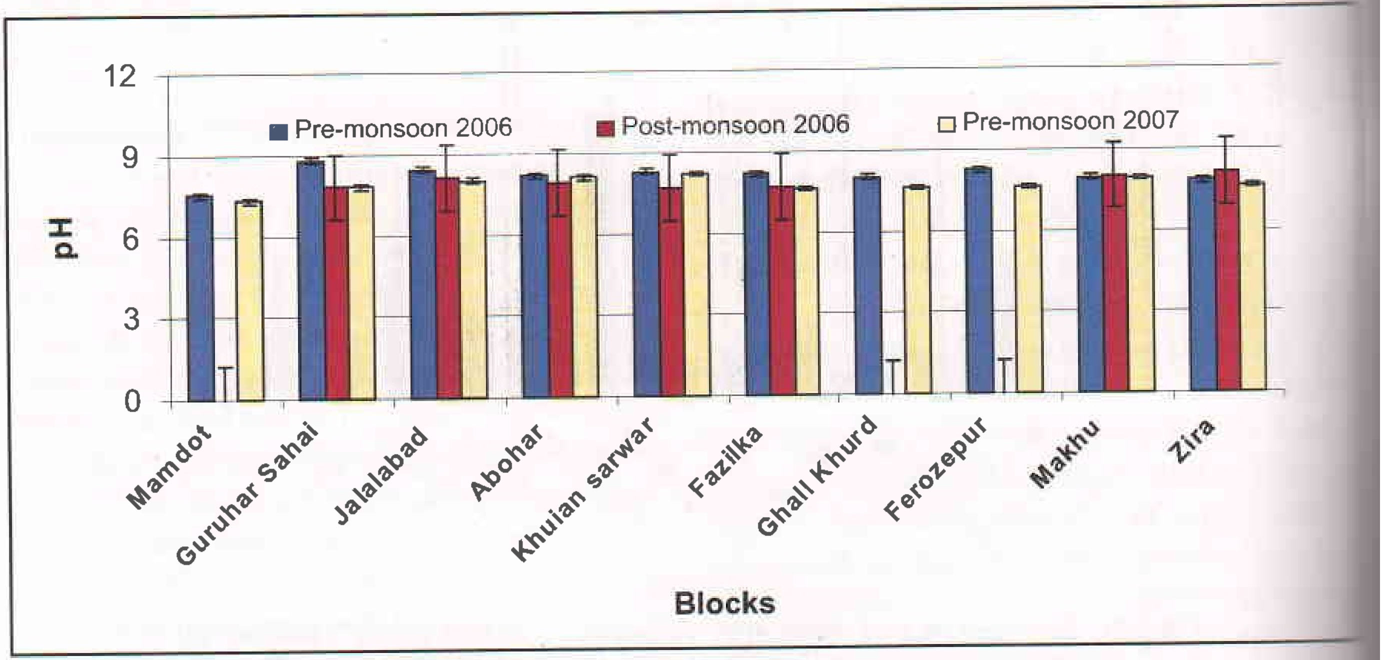


Fig. 6.6: Season-wise and block-wise variation in pH of groundwater

Variations in EC values of groundwater

There was significant variation in EC values of groundwater samples collected from different blocks in three different seasons (Fig. 6.7). On an average, the EC values of groundwaters of Jalalabad, Abohar, Khulan Sarwar and Fazilka blocks were higher than those of other blocks. The EC values of groundwater of different blocks of Ferozepur were far beyond the normal range of electrical conductivity, and would cause adverse effect on plant growth and also if used for drinking purposes. Although the variation was minor, it was observed that there was a tendency of increasing salinity in water with time, because in most cases the EC values increased in pre-monsoon 2007 samples as compared to the preceding seasons (Fig. 6.7).

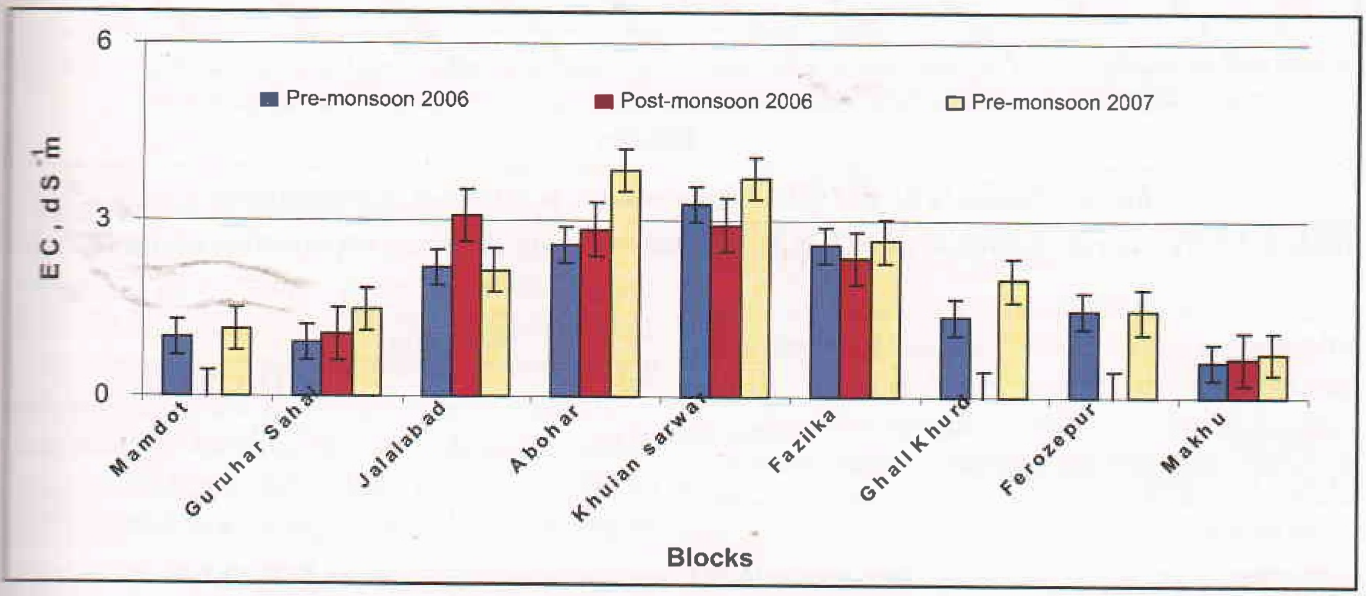
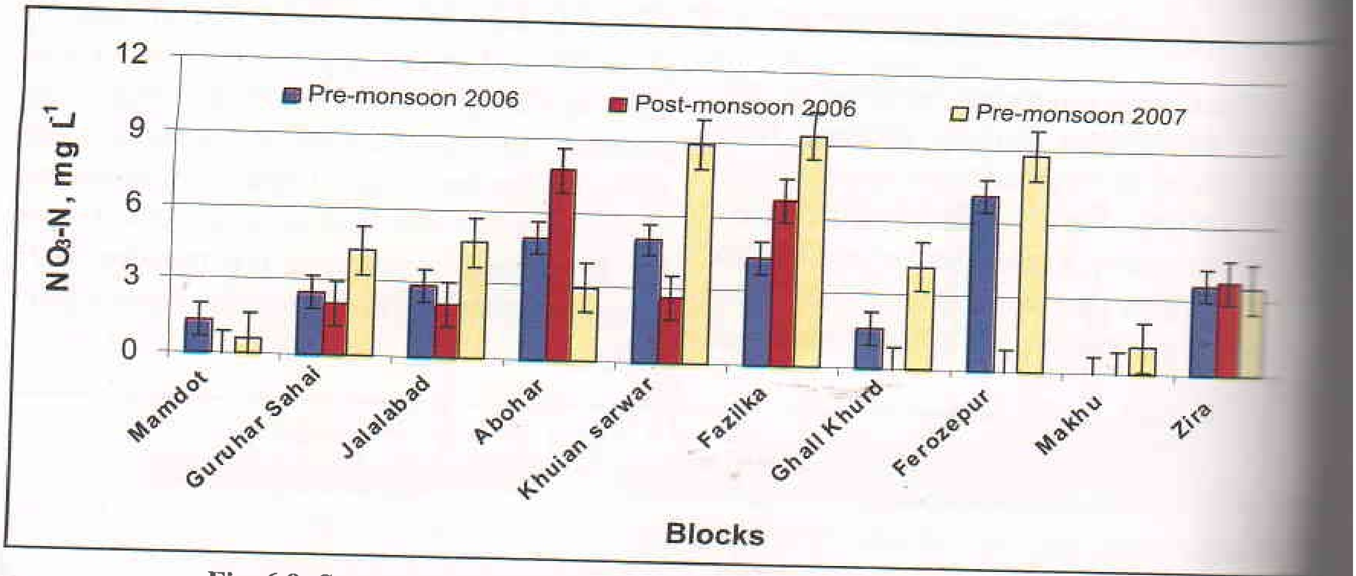


Fig. 6.7: Season-wise and block-wise variation in EC(dS m^{-1}) of groundwater

Variations in NO_3-N load of groundwater

There was significant variation in NO_3-N load of groundwater samples collected from different blocks in three different seasons (Fig. 6.8). On an average, the NO_3-N load of groundwater of Abohar, Khulan Sarwar, Fazilka and Ferozepur was higher than those of other blocks in all seasons, and the nitrate levels had an intimate link with the salinity of water. Although the NO_3-N load in groundwater samples collected from different blocks of the target district varied significantly, in 8per cent of the samples was well below the 10 mg L^{-1}, the threshold limit fixed by WHO for drinking purpose. There was always a significant variation in the NO_3-N load of groundwater samples collected from different sources in different seasons. In this case also there was an ascending tendency of nitrate contamination in water with time (Fig. 6.8). In general, with increasing depth of sampling aquifers, the NO_3-N loads of groundwater samples decreased.

Variations of NO_3-N concentration in irrigation waters during repeat sampling have been worked out in Table 6.27. Variations up to the extent of -46.66 to +14.15 during repeat sampling have been observed. Minimum variations have been observed in Guru har sahai, Jalalabad and Khuian sarwar blocks.



Fig, 6.8: Season-wise and block-wise variation in nitrate-N of groundwater

Table 6.27: Temporal variations of NO_3-N in ground waters in different blocks ofFerozepur

Block	Variation	
	1st - 2nd	1st - 3rd
Mamdot	No sampling	- 2.32 to +3.34
Guru har sahai	- 4.41to +4.88	-22.27 to +3.35
Jalalabad	- 7.40 to +9.66	- 31.99 to +8.65
Abohar	- 16.90 to +3.46	- 8.51 to +11.70
Khuian sarwar	- 5.28 to +3.22	-30.4 to +9.41
Fazilka	- 46.66 to +14.15	- 31.1 to +6.95
Ghall khurd	No sampling	- 25.4 to +3.27
Ferozepur	No sampling	- 32.0 to +20.0
Makhu	All Villages were changed	- 2.82 to +0.23
Zira	- 14.04 to +13.74	- 13.1 to +9.14
Overall	- 46.66 to +14.15	- 30.4 to + 20.0

- '- ive' sign means increase over 1st sampling
- '+ ive' sign means decrease over 1st sampling

6.2.3 Hooghly

Variations in pH of groundwater

There was significant variation in pH of groundwater samples collected from different blocks in three different seasons (Fig.6.9). On average, the pH of groundwater of Bolagar, Pandua and Chanditala-I blocks was higher than that of rest others compared. Results indicate the groundwater of different blocks of Hoog almost neutral in reaction. In general, pH val groundwater samples collected during monsoon season of 2006 was comparatively than pre-monsoon seasons of both the year and 2007).

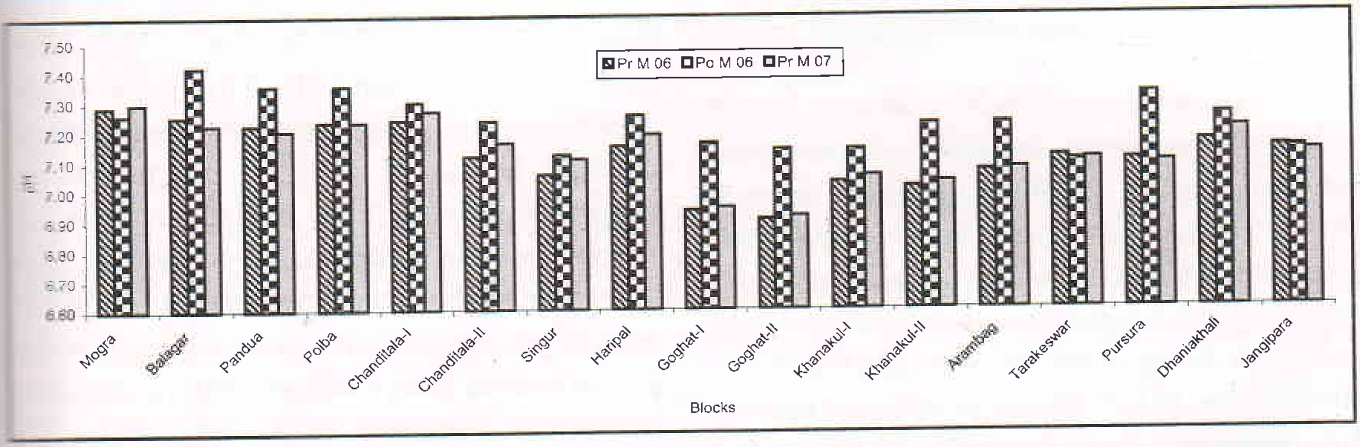


Fig. 6.9: **Season-wise and block-wise variation in pH values of groundwater (Pr M 06 = pre-monsoon season 2006, Post-M 2006 = post-monsoon season 2006 and Pre-M 2007 = pre-monsoon season 2007)**

Variations in EC values of groundwater

There was significant variation in EC values of groundwater samples collected from different blocks in three different seasons (Fig. 6.10). On average, the EC values of groundwater of Balagar, Jangipara and Mogra blocks were higher than these of blocks compared. However, results indicated that the EC values of groundwater of different blocks of Hooghly was within the normal range of electrical conductivity (< 1.dSm^{-1}), and would cause no adverse effect on plant growth and also if use for drinking purposes, so far salinity is concerned. Although the variation was minor, it was observed that there was always a higher value of EC of groundwater samples collected during pre-monsoon seasons of 2006 and 2007 than that of samples collected during post-monsoon season of 2006.

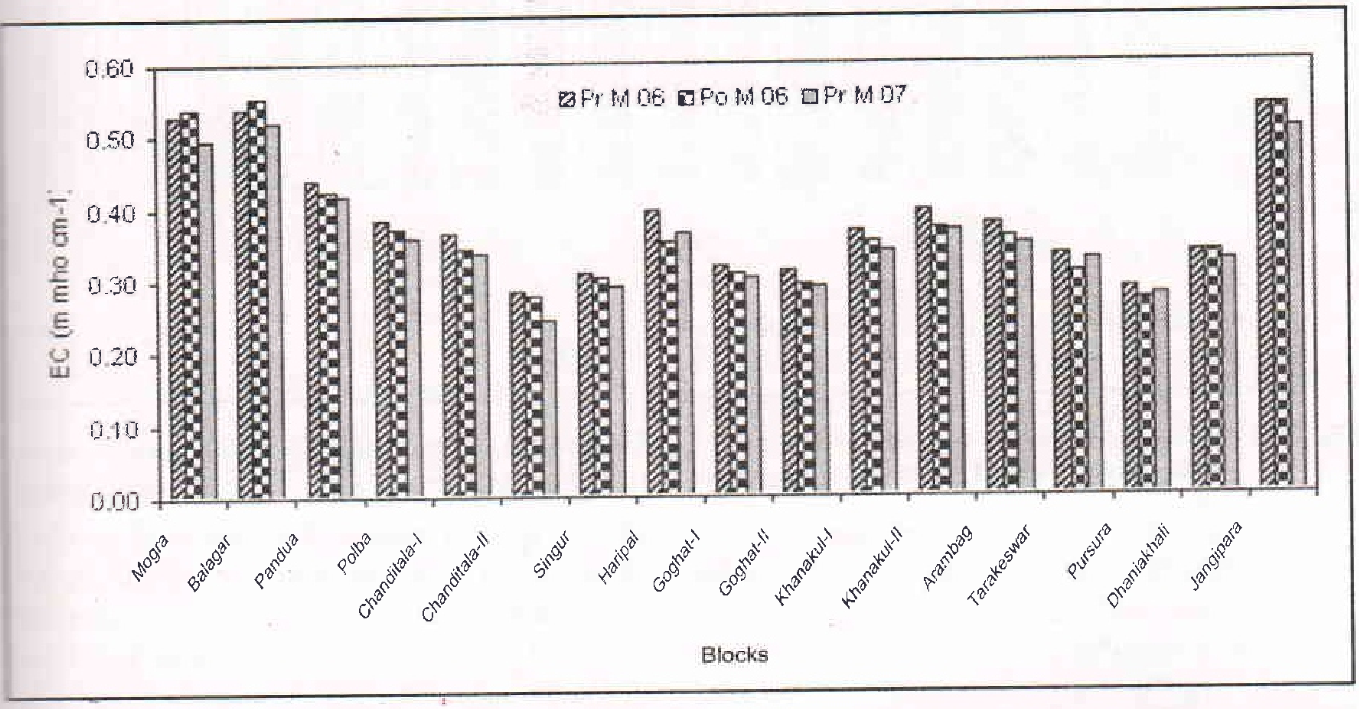


Fig. 6.10: **Season-wise and block-wise variation in EC values of groundwater (Pr M 06 = pre-monsoon season 2006, Post-M 2006 = post-monsoon season 2006 and Pre-M 2007 = pre-monsoon season 2007)**

Variations in NO_3-N load of groundwater

There was significant variation in NO_3-N load of groundwater samples collected from different blocks in three different seasons (Figs.6.11 and 6.12). On average, the NO_3-N load of groundwater of Arambag, Dhaniakhali, Polba and Haripal was higher than those of other blocks compared during both the seasons (Fig. 6.11). Although the NO_3-N load in groundwater samples collected from different blocks of the studied district varied significantly, its load was well below the 10 mg L^{-1}, the threshold limit fixed by WHO for drinking purpose. There was always a significant variation in the NO_3-N load of groundwater samples collected from different sources in different seasons (Table 6.28). In general, with increasing depth of sampling aquifers, the NO_3-N loads of groundwater samples decreased. This was true for both the years (2006 and 2007) and seasons (pre and post-monsoon) of sampling.

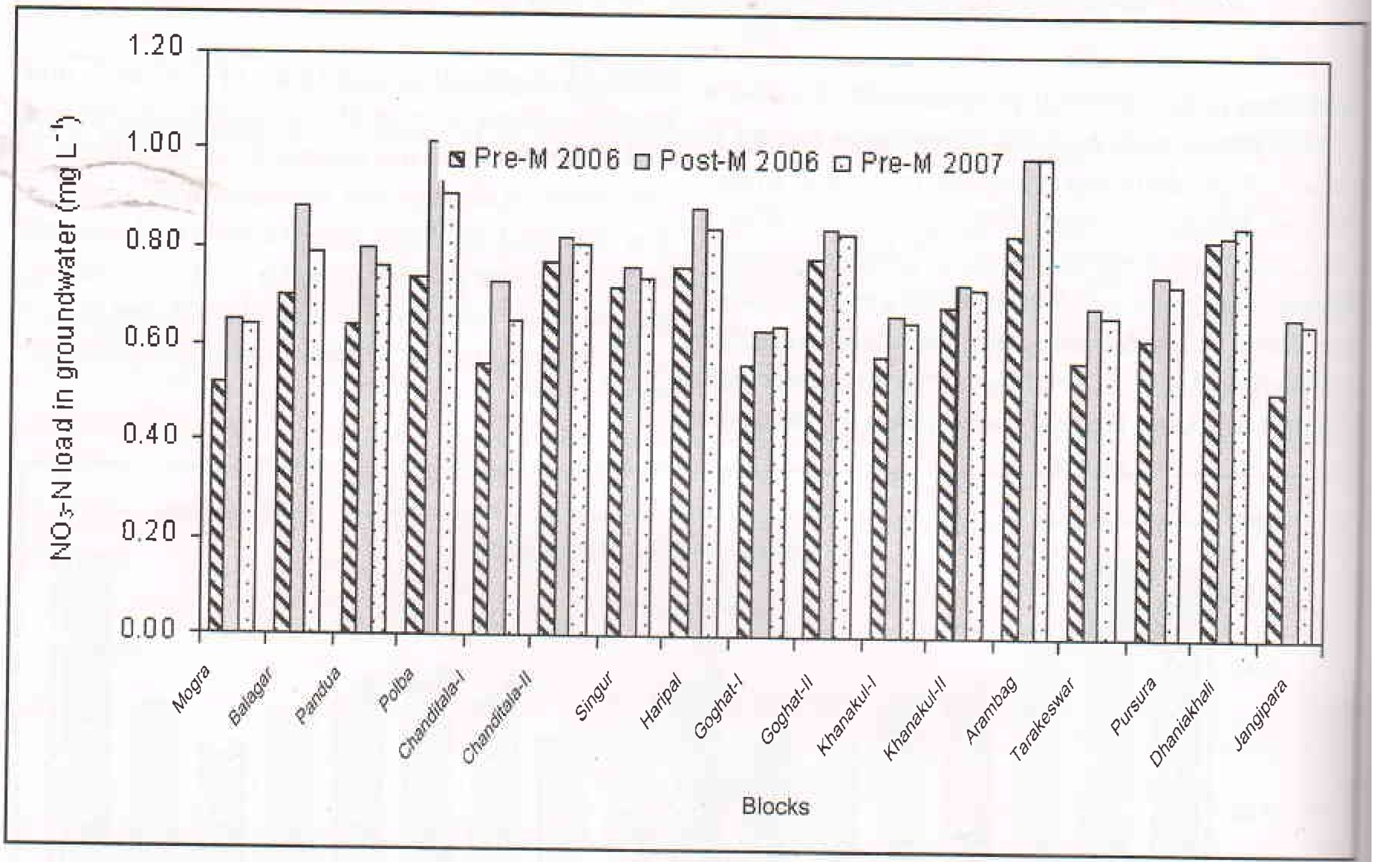


Fig. 6.11: Season-wise and block-wise variation in NO_3-N loading in groundwater (Pr M 06 = pre-monsoon season 2006, Post-M 2006 = post-monsoon season 2006 and Pre-M 2007 = pre-monsoon season 2007)

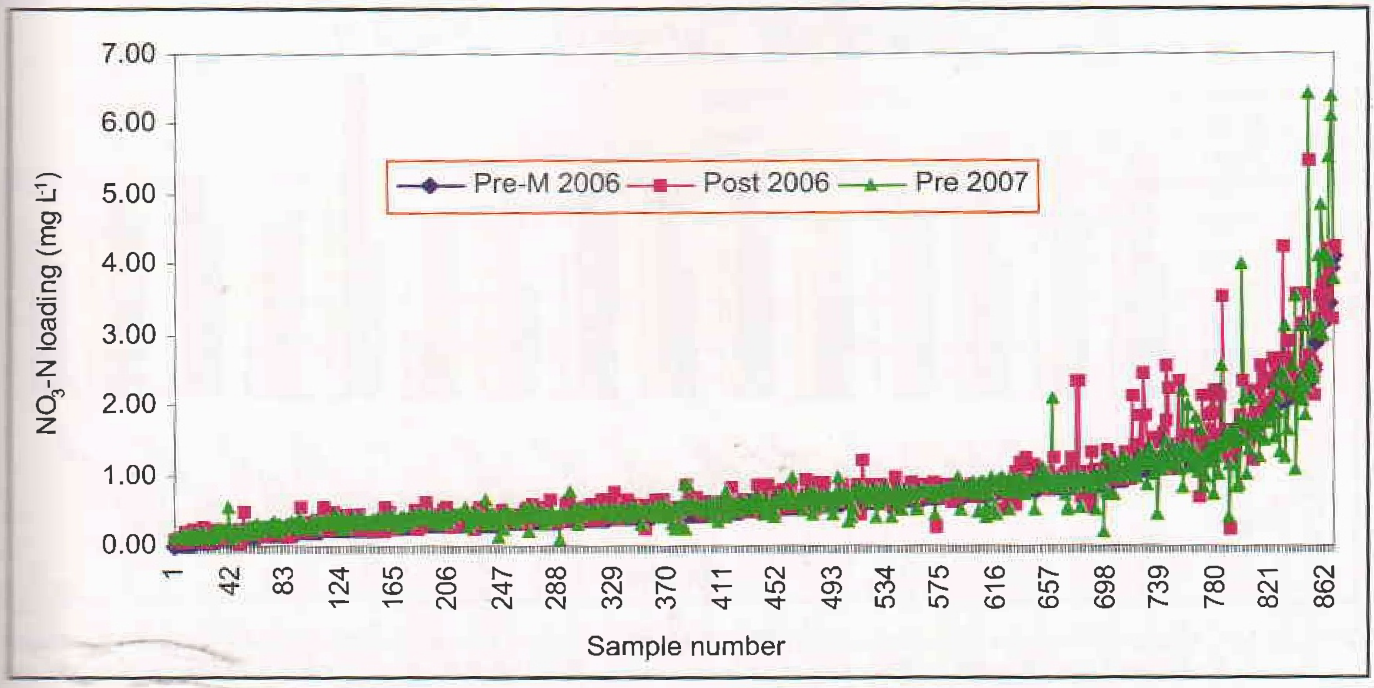


Fig. 6.12: Temporal variations of NO_3-N loading in groundwater samples

Table 6.28: Overall variations in NO_3-N (mg L^{-1}) loading of water samples collected from different sampling aquifer depths in different seasons

	NO_3-N (Pre-M) (mg L^{-1})			NO_3-N (Post-M) (mg L^{-1})			NO_3-N (Pre-M) (mg L^{-1})		
Source (nos)	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**
Well (8)	0.88-2.01	1.29	0.43	0.92-2.16	1.64	0.55	0.54-2.12	1.35	0.52
TW (470)	0.04-4.05	0.95	0.63	0.08-5.47	1.12	0.77	0.10-6.42	1.05	0.82
STW (258)	0.02-4.12	0.40	0.35	0.06-4.25	0.47	0.37	0.11-3.79	0.48	0.32
MDTW (57)	0.06-0.65	0.31	0.14	0.12-0.88	0.38	0.17	0.11-0.69	0.41	0.12
DTW (75)	0.01-0.53	0.19	0.10	0.04-0.77	0.25	0.14	0.09-0.62	0.28	0.10

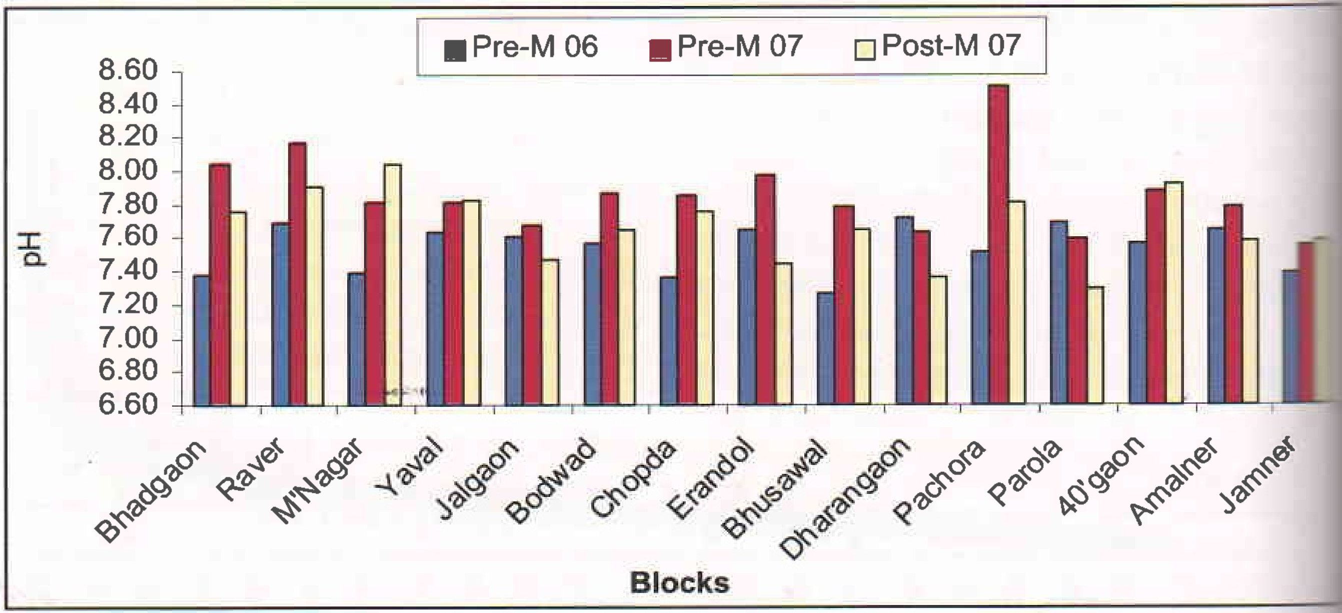
5.2.4 Jalgaon

Variations in pH of groundwater

There was significant variation in pH of groundwater samples collected from different blocks in three different seasons (Fig. 6.13). On average, the pH of groundwater of Dharangaon, Bhusawal, Amalner and Jamner blocks was higher than that of rest others compared. Results indicated that the groundwater of different blocks of Jalgaon district is almost neutral to slightly alkaline in reaction. In general, pH values of groundwater samples collected during pre-monsoon season of 2006 was comparatively lower than pre and post monsoon seasons of the year 2007.

Variations in EC of groundwater

There was significant variation in EC values of groundwater samples collected from different blocks in three different seasons (Fig. 6.14). On average, the EC values of groundwater of Dharangaon, Bhusawal, Amalner and Jamner blocks were higher than that other blocks compared. In general, results indicated that the EC



FFig. 6.13: Season-wise and block-wise variation in pH values of groundwater (Pr M 06 = pre-mon season 2006, Pre-M 2007 = pre-monsoon season 2007 and Post-M 2006 = post-monsoon sea 2007)

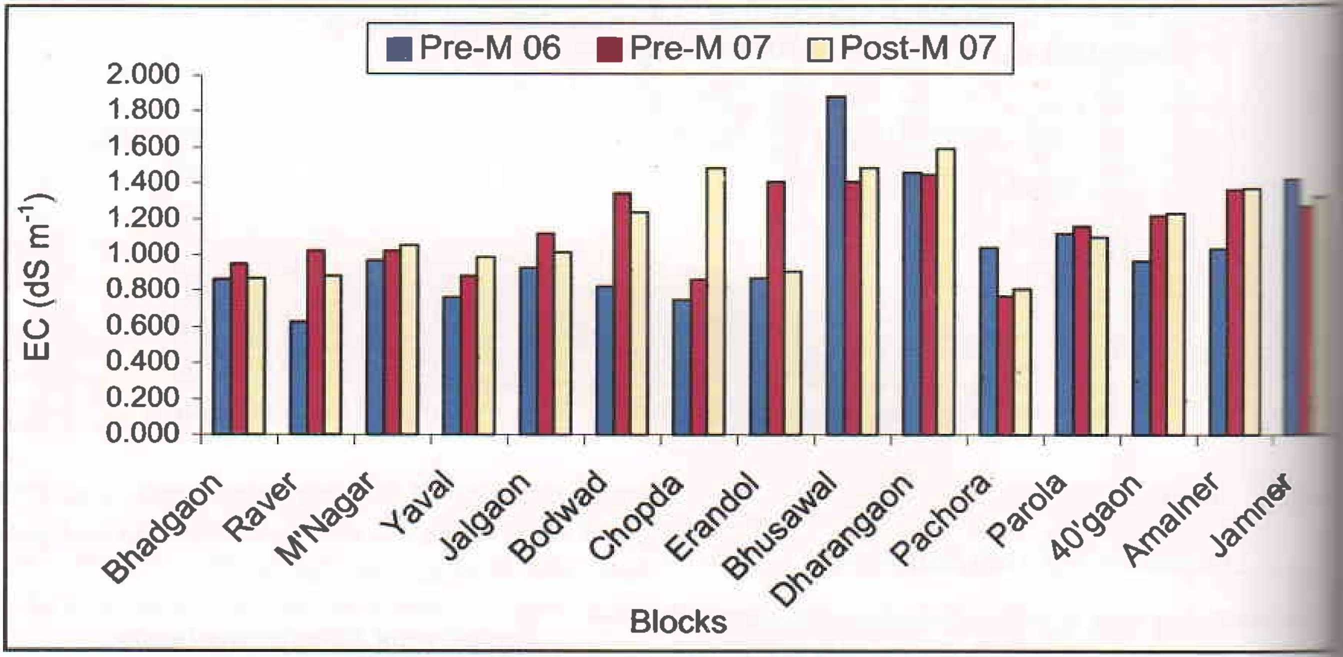


Fig. 6.14: Season-wise and block-wise variation in EC values of groundwater (Pr M 06 = pre-monsoon se 2006, Pre-M 2007 = pre-monsoon season 2007 and Post-M 2006 = post-monsoon season 2007)

values of groundwater of most of blocks of Jalgaon district was within the normal range of electrical conductivity (< 1.0 dSm-1), but in some blocks it was slightly higher than 1.0 dSm^{-1} Although the variation was minor, it was observed that slig higher value of EC of groundwater samp collected during pre and post-monsoon seaso 2007 as compared to pre-monsoon 2006.

5.2.5 Coimbatore

pH of groundwater

In all the three season, there was significant variation in pH of groundwater samples collected from different blocks (Fig. 6.15). Results showed that groundwater of different blocks of Coimbatore is neutral to slightly alkaline in reaction. Irrespective of the seasons and blocks, there was an increasing trend from post-monsoon 2006 to post-monsoon 2007 and slightly higher pH values were observed during post monsoon-2007.

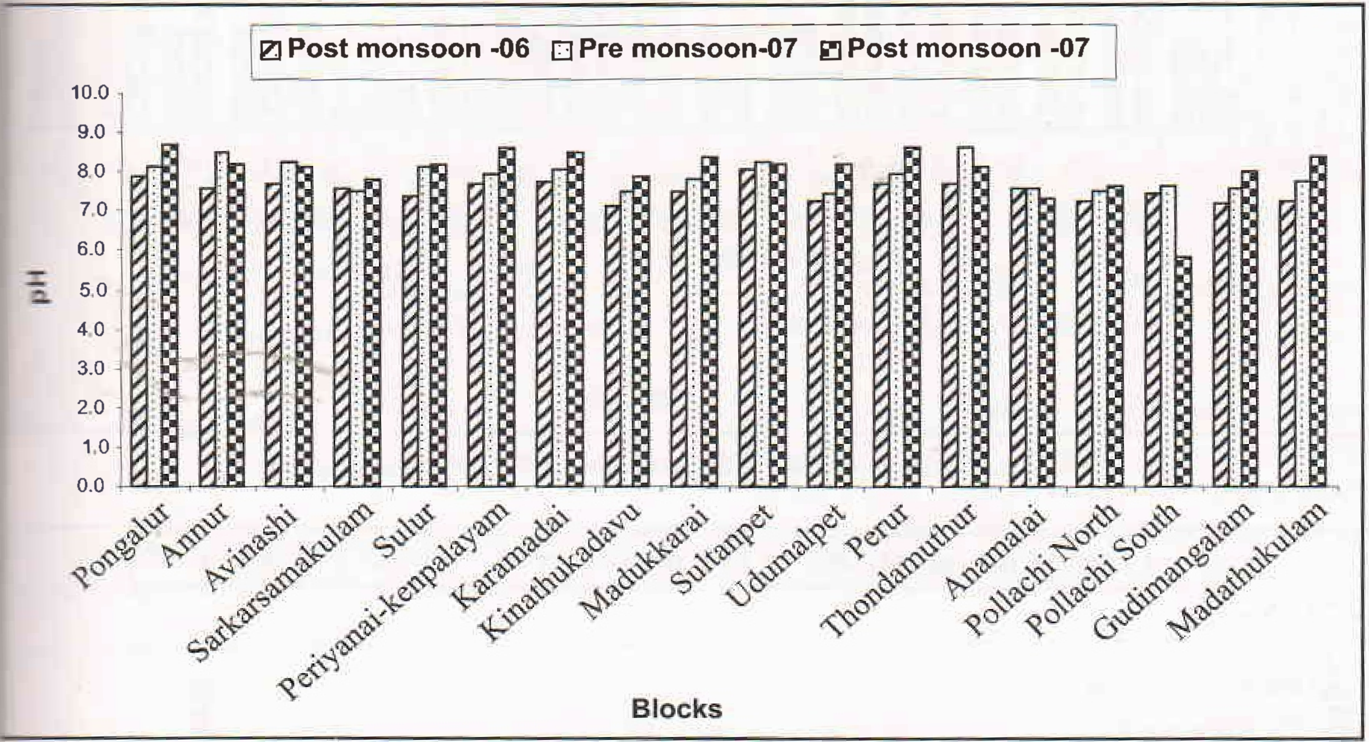


Fig. 6.15: Season-wise and block-wise variation in pH values of groundwater

EC of groundwater

The mean EC values of different blocks of Coimbatore district varied from 0.93 to 3.5 dS m^{-1}. Irrespective of the seasons, there was a significant variation in EC values of groundwater samples collected from different blocks (Fig. 6.16). Although the variation was minor, it was observed that there was always a higher value of EC of groundwater samples collected during post-monsoon seasons of 2006 and 2007 than that of samples collected during pre-monsoon season of 2007.

Nitrate-N content of groundwater

The season-wise and block-wise variation in NO_3-N content of groundwater samples is shown in Fig. 6.17. The mean NO_3-N values of different blocks varied from 4.45 to 12.21 mg L$^{-1.}$ Irrespective of the seasons and blocks, there was a significant variation in the NO_3-N content of groundwater samples was observed. In general, the higher NO_3-N content was recorded during the post monsoon season of 2006 and 2007.

Temporal variation in NO_3-N content of the representative aquifers of the selected sites were shown in Fig. 6.18. The temporal variation in NO_3-N content of ground water samples was observed, being higher in post monsoon-2007 than in pre monsoon -2007.

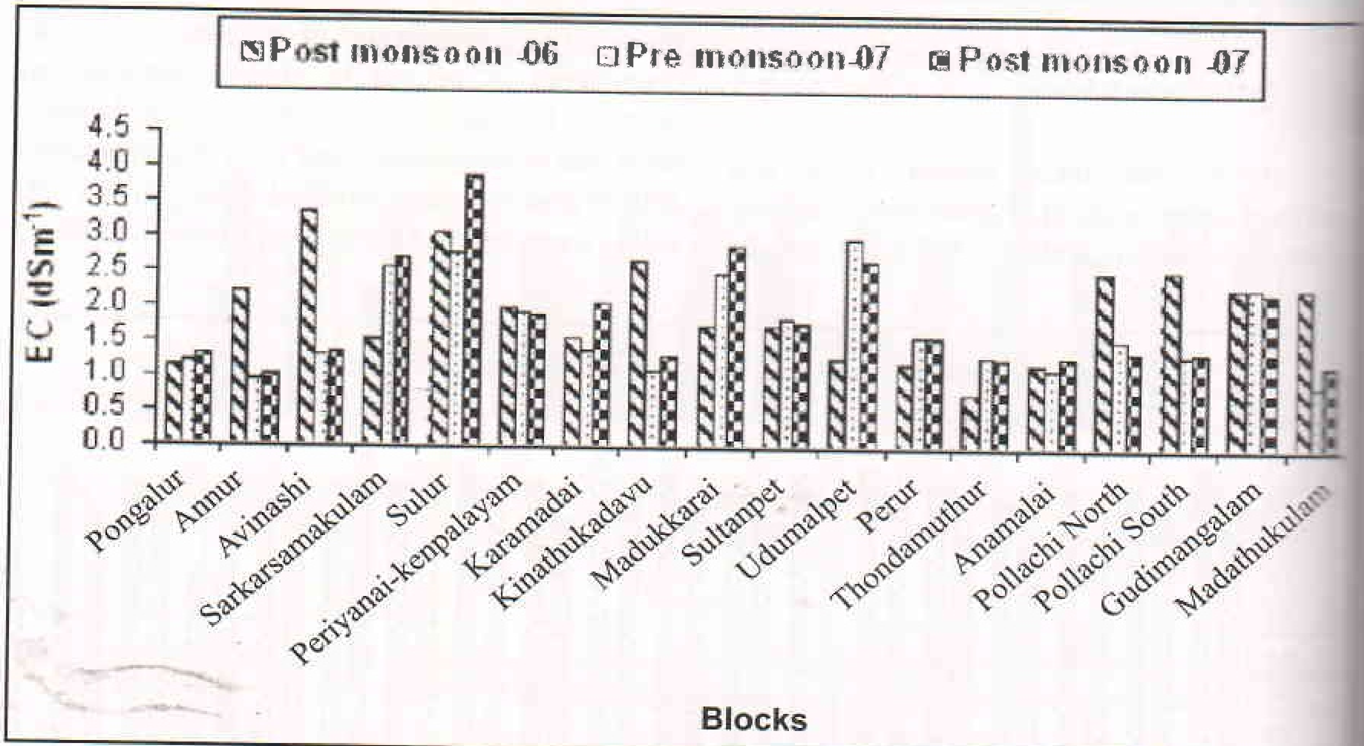


Fig. 6.16: Season-wise and block-wise variation in EC values of groundwater

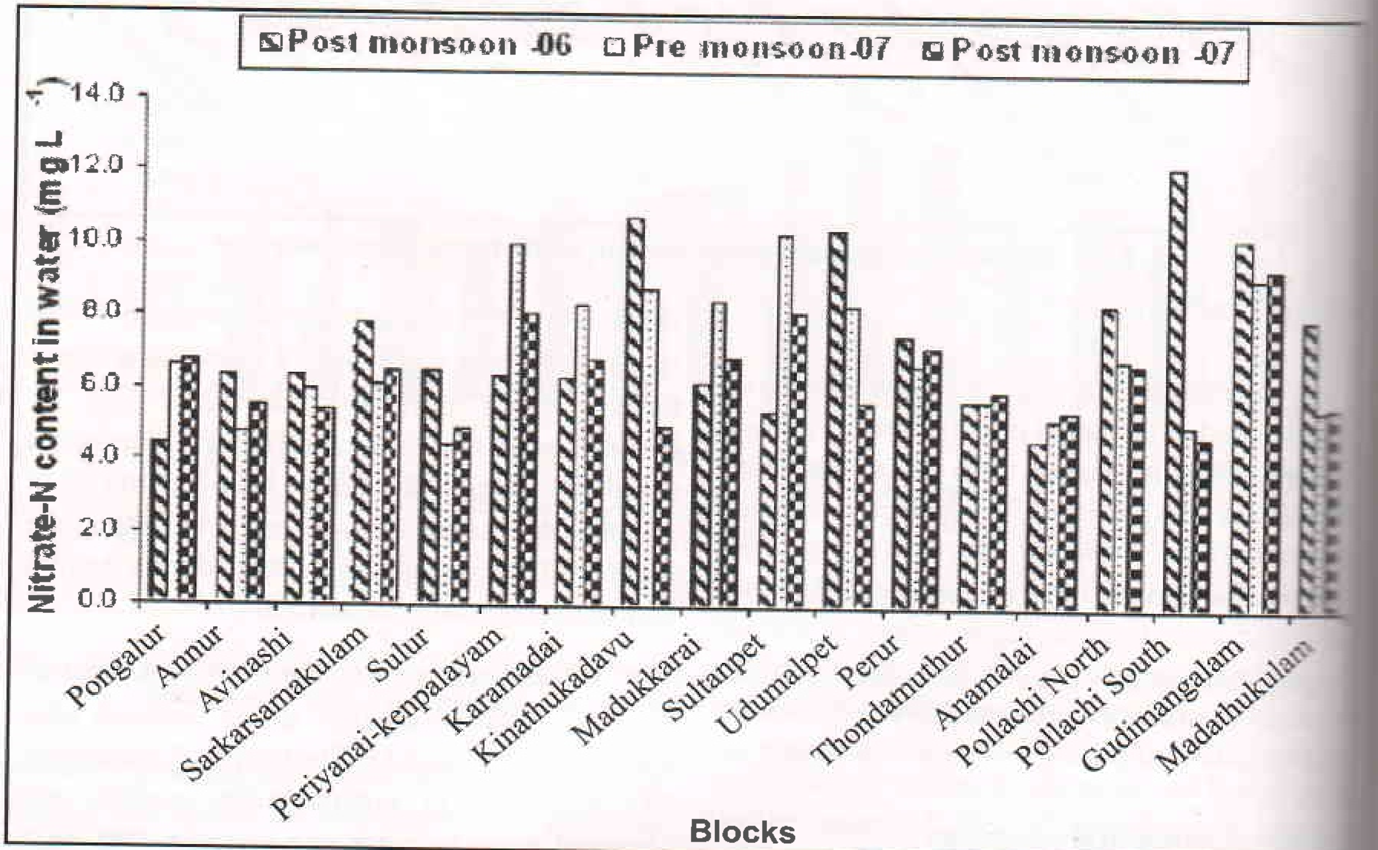


Fig. 6.17: Season-wise and block-wise variation in NO_3-N loading in groundwater

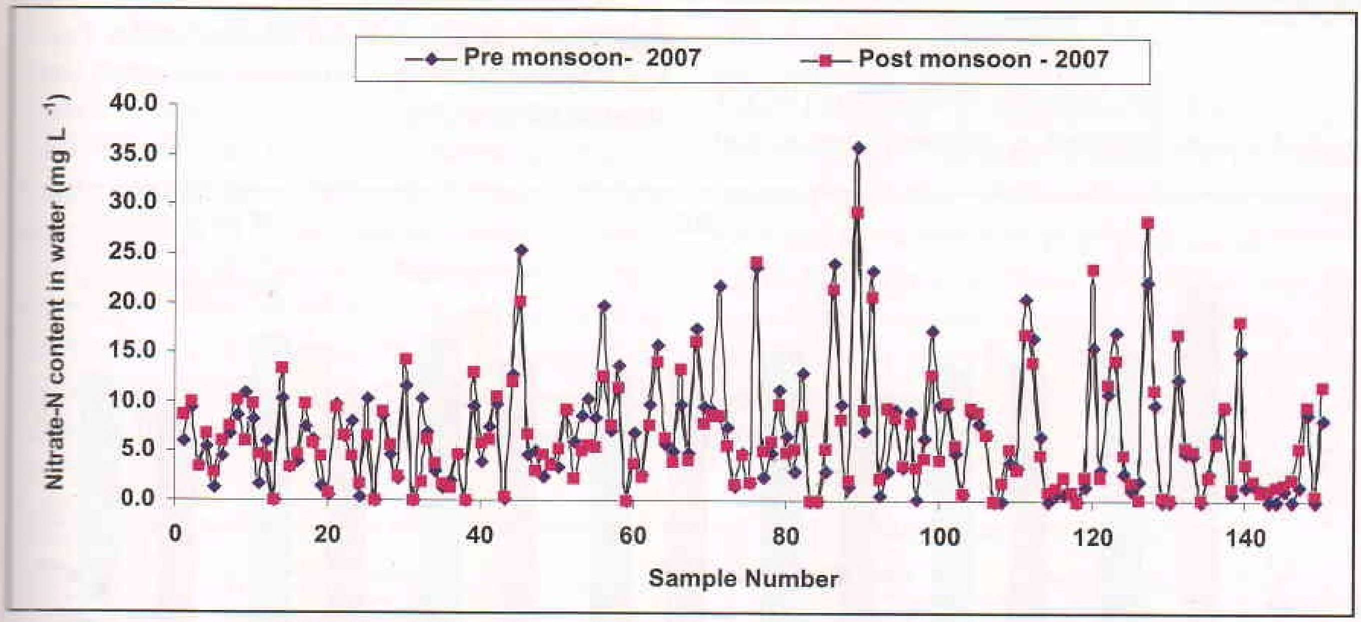


Fig. 6.18: Temporal variations of NO_3-N loading in groundwater samples

5.2.6 Hoshangabad

Variation in pH of groundwater

Barring a few exceptions there was no significant variation in pH of groundwater samples collected from different blocks in three different seasons (Fig. 6.19). Results showed that the groundwater of different blocks of Hoshangabad is neutral to slightly alkaline in reaction, and the reaction did not change significantly with time.

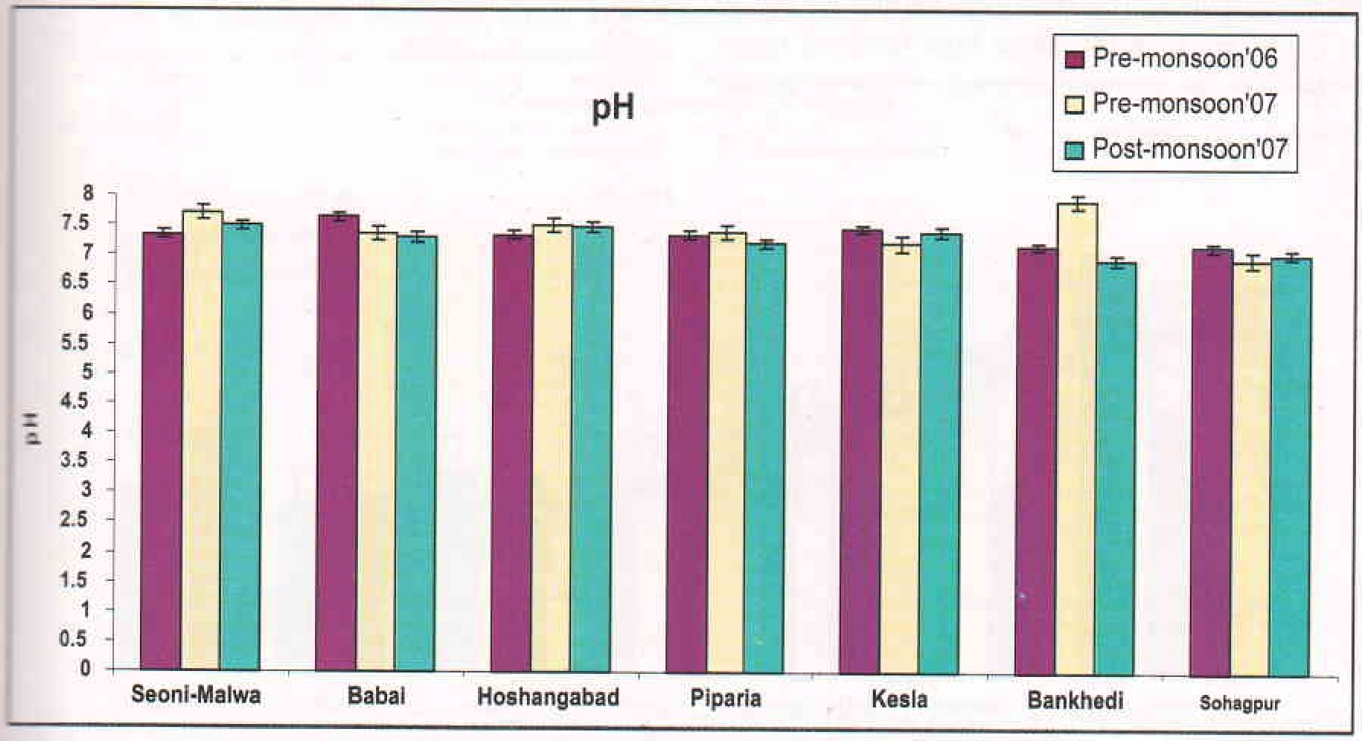


Fig.6.19: Temporal variation in pH of water

Variation in EC of groundwater

Unlike pH, electrical conductivity (EC) of ground waters collected at different seasons had significant variations in all blocks except Baba and Piparia although no particular trend was observed (Fig. 6.20).

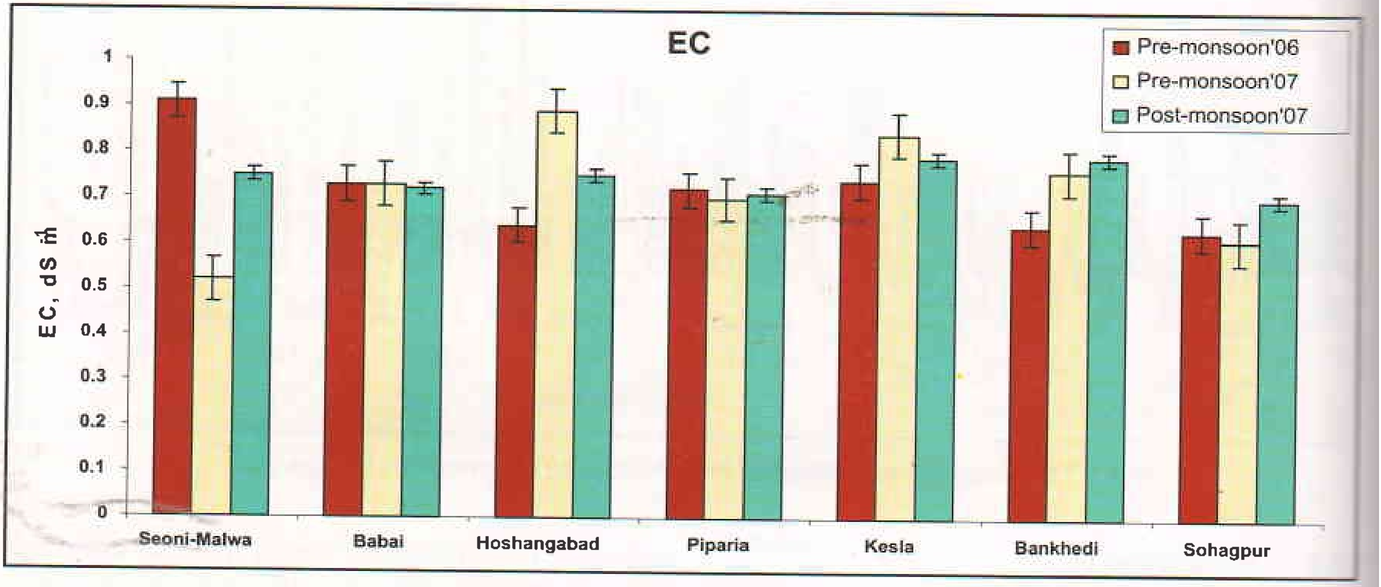


Fig.6.20: Temporal variation in EC of water

Variation in nitrate-N content of groundwater

The season-wise and block-wise variation in NO_3-N content of groundwater samples is shown in Figure 6.21. In blocks of high fertilizer usage there was an increasing trend in mean nitrate concentration in groundwater samples with time, whereas in blocks of medium to low fertilizer usage the mean nitrate concentration in ground waters either remained unchanged or decreased significantly with time.

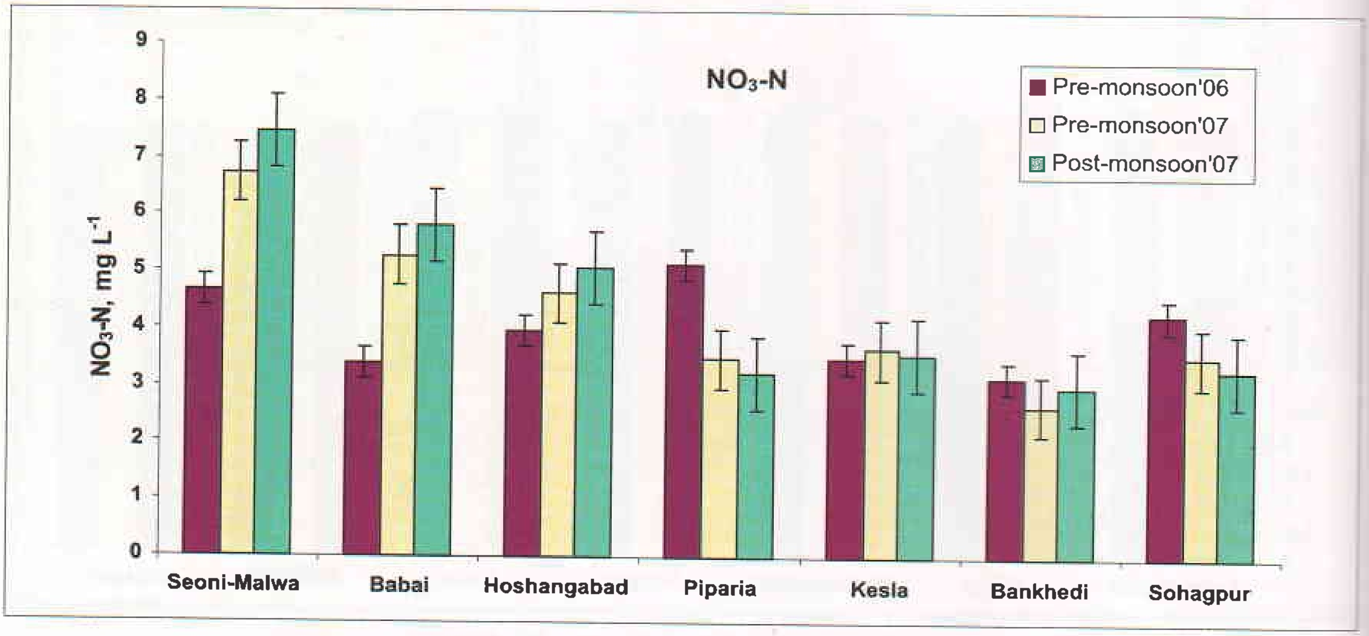


Fig.6.21: Temporal variation in nitrate content of groundwater

The spots from which 522 water samples were drawn in pre-monsoon of 2007 were re-visited in post-monsoon of 2007 with the help of GPS to study the temporal variation in level of nitrate contamination of ground waters. Nitrate concentrations of all the samples collected during post-monsoon of 2007 have been presented with reference to those recorded during pre-monsoon of 2007 in Figures 6.22 (up to 5 mg N L^{-1}), 6.23 (5-10 mg N L^{-1}) and 6.24 (>10 mg N L^{-1}). A close scrutiny of these figures indicated that in most of the sampling sites, there were increases in nitrate contamination, although quite a large number of sites recorded a decrease too in nitrate contamination. Greater percentage of water sources recording increase in nitrate content belonged to the category of polluted samples (>10 mg N L^{-1}) (Fig.6.24).These data along with the overall mean nitrate concentrations of pre- and post-monsoon samples (Table 6.29) suggested a significant increase in nitrate contamination level in post-monsoon samples over the pre-monsoon samples.

Table 6.29: Level of nitrate contamination (mg NO_3-N L^{-1}) in water from different blocks.

Season	Pre-monsoon 2006			Pre-monsoon 2007			Post-monsoon 2007		
Block	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Seoni-malwa	0-15.9	4.3	3.80	0-48.4	6.7	8.80	0-61.4	7.40	10.80
Babai	0-11.0	3.9	2.02	0-60.4	5.3	7.45	0-88.9	5.8	11.10
Hoshangabad	0-13.9	4.0	3.20	0-61.8	4.6	6.81	0-86.5	5.0	9.21
Piparia	0-17.1	8.1	3.96	0-37.4	3.4	5.45	0-20.6	3.2	3.76
Kesla	0-13.9	3.4	3.20	0-43.9	3.6	5.29	0-43.9	3.5	5.20
Bankhedi	0-9.8	3.5	2.29	0.2-8.5	2.7	1.79	0-13.7	3.0	2.44
Sohagpur	1.0-8.4	3.3	2.46	0-10.4	3.5	2.85	0-10.4	3.2	2.64
Total	0-17.1	4.4	3.30	0-61.8	4.6	6.70	0-88.9	4.9	8.42

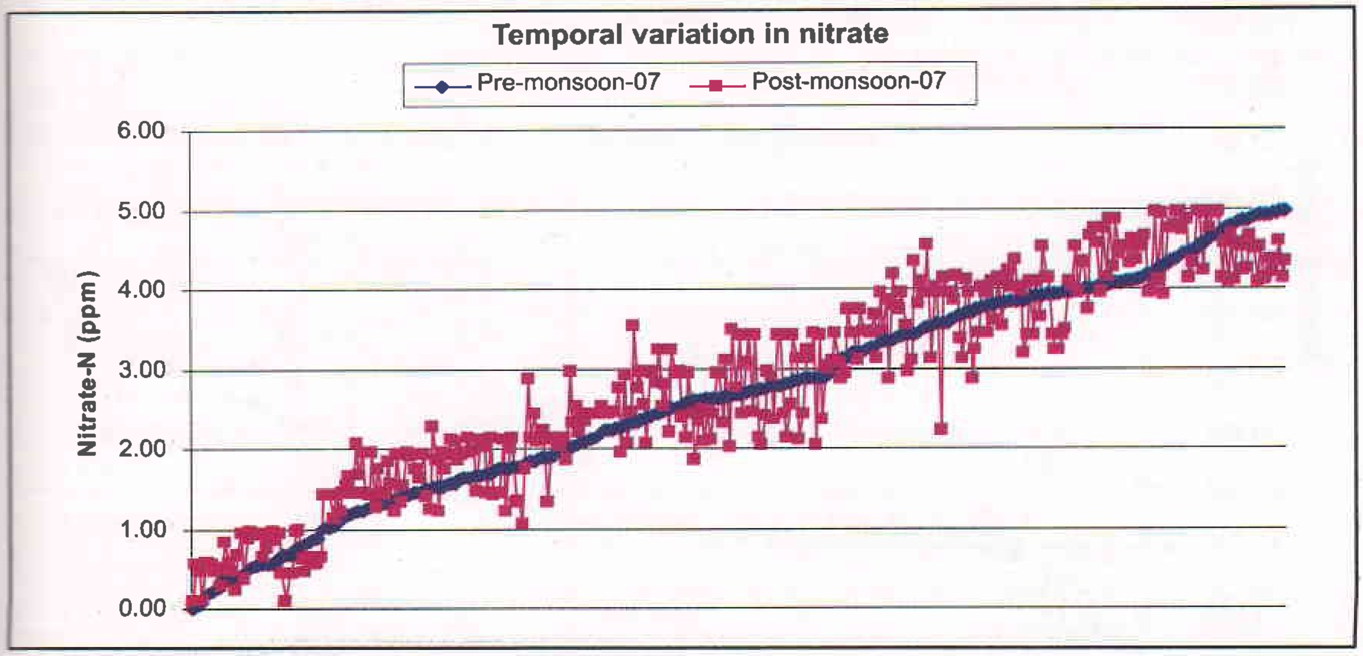


Fig. 6.22: Nitrate contents in groundwater samples (up to 5 mg N L^{-1}) collected during pre- and post-monsoon of 2007

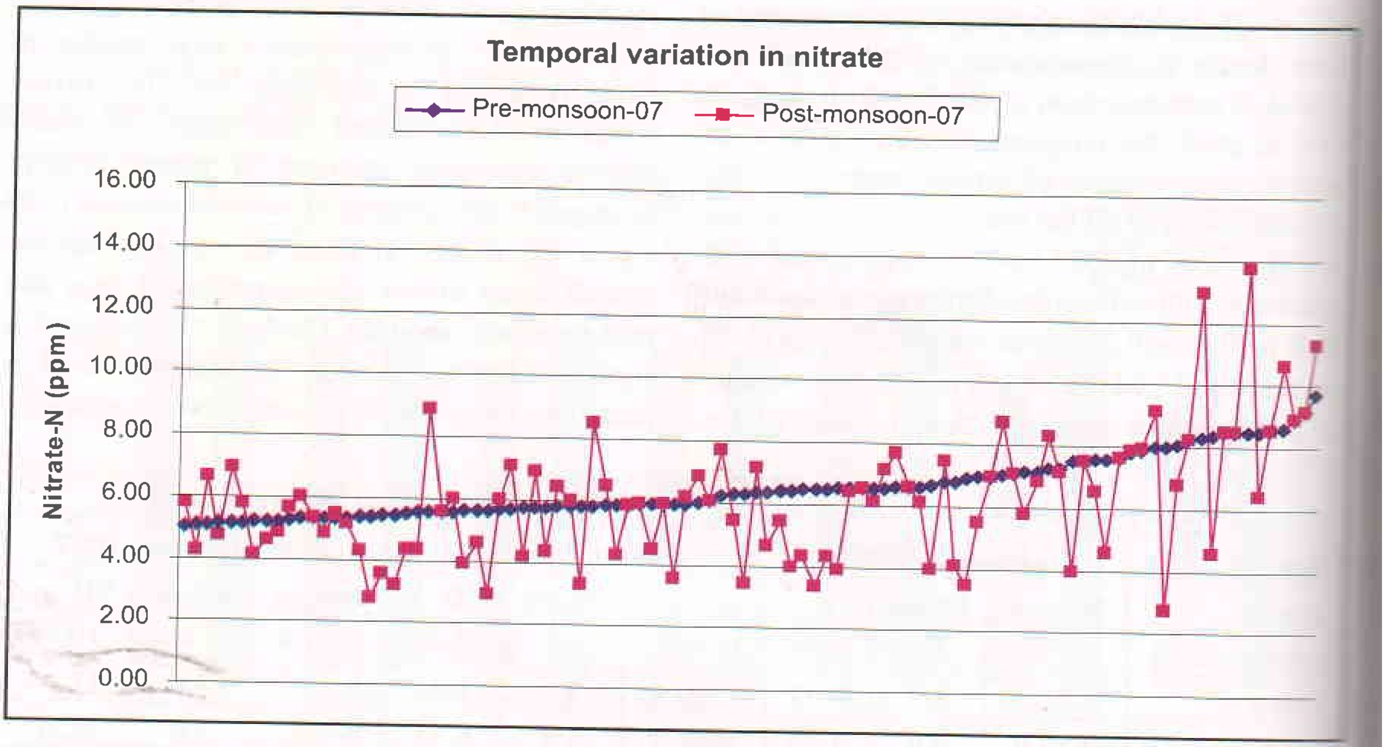


Fig.6.23: Nitrate contents in groundwater samples (5-10 mg N L^{-1}) collected during pre- and post-monsoon 2007

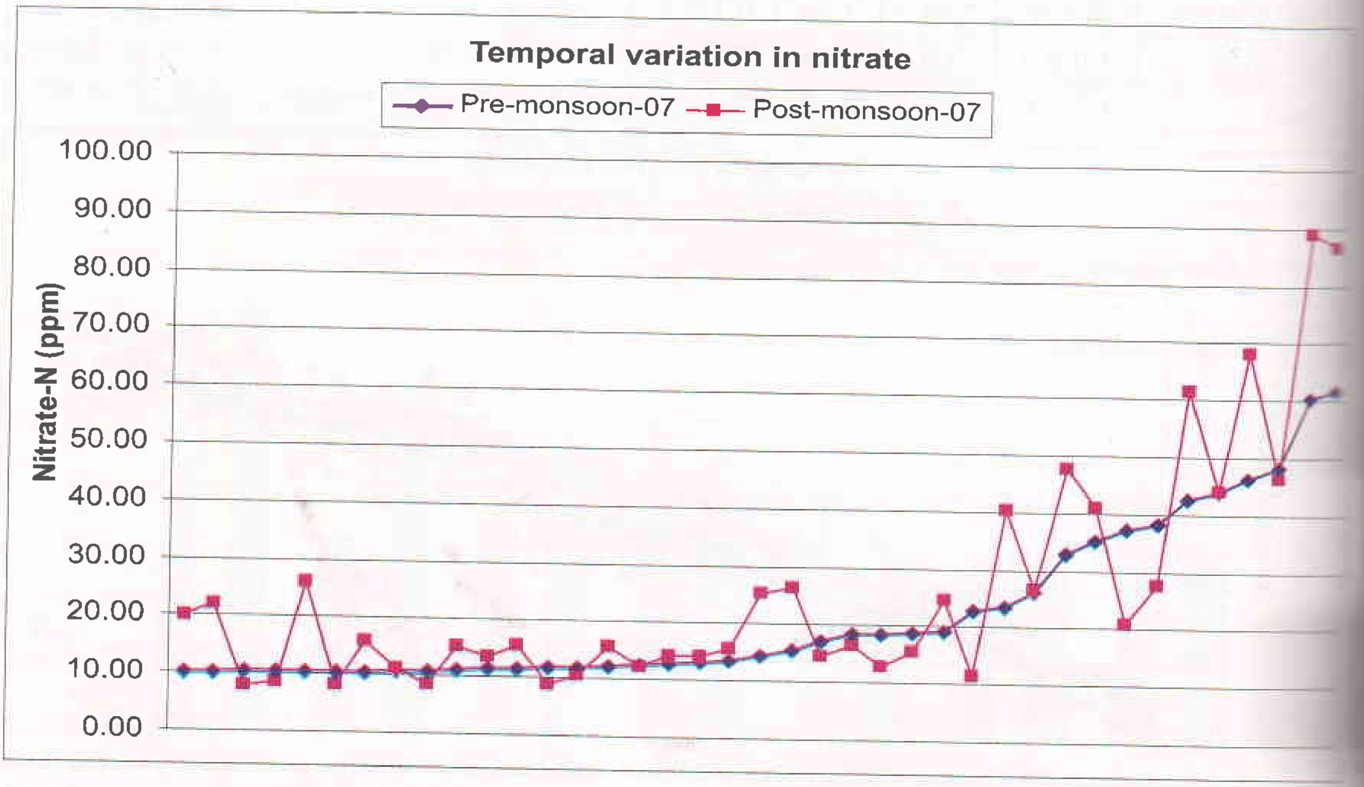


Fig.6.24: Nitrate contents in groundwater samples (>10 mg N L^{-1}) collected during pre- and post-monsoon 2007

6.3 Distribution of NO_3-N in the soil profiles of the selected sites

6.3.1 West Godavari

Soil sampling and analysis

Horizon-wise (0-20, 20-40 and 40-60cm) variations in pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (AN), NO_3-N content, clay, sand and silt content of the 48 soil profiles were studied. It was observed that with the increase in depth, pH and clay content of the soils increased and those of EC, organic C, total N, NO_3-N, sand and silt contents decreased (Tables 6.30 and 6.31). Samples of Undrajavaram mandal recorded the highest NO_3 -N content through out the profile (Table 6.32).

Table 6.30: Depth-wise variations in pH, EC, OC and available N content of soils

Soil depth (cm)	pH			EC (dSm^{-1})			OC (%)			AvailableN (kg ha^{-1})		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	5.94-8.67	7.21	0.78	0.12-3.14	0.67	0.57	0.31-1.92	0.96	0.38	284-488	362	46.92
20-40	6.30-8.70	7.59	0.58	0.15-2.45	0.74	0.50	0.23-1.37	0.79	0.25	235-420	316	49.98
40-60	6.4-9.2	7.74	0.85	0.11-2.26	0.58	0.46	0.18-1.23	0.68	0.22	205-395	298	47.56

Table 6.31: Depth-wise variations in NO_3-N, sand, silt and clay content of soils

Depth (cm)	NO_3 -N (mg kg^{-1})			Sand %			Silt %			Clay %		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	3.11-99.58	17.43	19.24	14.4-63.14	35.31	12.28	9.36-31.25	22.61	7.77	25.6-62.87	42.62	7.30
20-40	0.42-62.63	12.06	11.01	12.4-52.36	32.36	11.25	8.56-28.36	21.36	6.58	28.6-65.32	44.36	7.86
40-60	025-52.36	10.35	9.35	11.0-49.32	29.32	10.32	7.96-26.35	19.25	5.68	28.36-68.96	46.25	8.25

Table 6.32: Depth-wise NO_3-N (mg kg^{-1}) variations in soil profiles

S No	Mandal	Fertility status	Depth in cm					
			0-15	15-30	30-60	60-90	90-120	120-150
1	Kalla	Low	2.85	3.56	4.25	6.52	4.26	3.65
2	Penugonda	Medium	4.56	7.58	8.65	8.85	6.54	6.12
3	Undi	Medium	4.28	5.26	8.36	9.25	8.59	8.69
4	Bhimavaram	High	8.25	6.85	9.25	11.21	10.2	9.35
5	Undi	High	18.25	14.35	19.25	17.35	15.36	13.85
6	Ungaturu	High	10.85	9.25	13.25	14.32	13.52	12.25
7	Ungaturu	High	13.25	12.14	11.32	15.23	12.36	11.32
8	Tadepalligudem	High	21.85	18.36	19.32	21.35	24.32	18.96
9	Undrajavaram	High	89.69	58.24	74.59	81.25	58.21	41.36
10	Poduru	High	6.85	1.35	4.52	5.23	2.85	3.12

6.3.2 Ferozepur

Soil sampling and analysis

pH and EC (Soil:Water ::1:2) range, mean values and standard deviations of different depths of soils up to 60 cm are shown in Table 6.33. In this district soil pH varied from 6.7 to 9.7, 7.0 to 9.8 and 6.8 to 9.9 with mean values of 8.85, 8.88 and 8.95 in 0-20, 20-40 and 40-60 cm depths of soils, respectively. Electrical conductivity of soils varied

Table 6.33: Range and mean values of pH and EC of soil samples

Block	Depth (cm)	pH			EC (dSm^{-1})		
		Range	Mean	S.D.	Range	Mean	S.D.
Mamdot	0-20	8.4-8.7	8.56	0.10	0.24-0.90	0.60	0.24
	20-40	8.7-9.0	8.81	0.11	0.25-0.68	0.41	0.15
	40-60	7.5-9.0	8.56	0.54	0.21-0.75	0.46	0.20
Guru har sahai	0-20	8.8-9.7	9.42	0.34	0.32-0.58	0.46	0.09
	20-40	9.3-9.8	9.52	0.19	0.25-0.55	0.41	0.11
	40-60	9.0-9.9	9.50	0.34	0.25-0.50	0.38	0.09
Jalalabad	0-20	8.9-9.6	9.12	0.26	0.36-0.95	0.58	0.20
	20-40	9.0-9.5	9.24	0.17	0.38-0.70	0.49	0.10
	40-60	9.1-9.5	9.22	0.15	0.38-0.66	0.50	0.10
Abohar	0-20	8.8-9.1	9.00	0.11	0.20-0.68	0.36	0.17
	20-40	8.8-9.6	9.12	0.32	0.21-0.60	0.41	0.12
	40-60	8.7-9.4	9.04	0.27	0.27-1.57	0.62	0.48
Khuian sarwar	0-20	8.5-9.3	8.78	0.30	0.25-3.31	1.42	1.36
	20-40	7.0-9.5	8.48	0.83	0.20-3.28	1.33	1.32
	40-60	8.5-9.4	8.82	0.33	0.17-3.50	1.41	1.43
Fazilka	0-20	9.0-9.7	9.30	0.24	0.27-1.35	0.64	0.38
	20-40	8.9-9.7	9.24	0.27	0.32-1.33	0.61	0.37
	40-60	8.8-9.7	9.22	0.29	0.29-1.20	0.61	0.32
Ghall khurd	0-20	8.2-9.5	8.78	0.49	0.36-0.92	0.61	0.20
	20-40	8.7-9.6	9.06	0.32	0.24-0.74	0.40	0.18
	40-60	8.7-9.6	9.12	0.29	0.27-0.48	0.39	0.07
Ferozepur	0-20	6.7-9.1	8.18	0.85	0.23-2.45	0.71	0.87
	20-40	7.0-8.6	8.00	0.66	0.18-2.68	0.88	0.93
	40-60	6.8-9.4	8.32	0.86	0.18-2.32	1.09	1.00
Makhu	0-20	8.3 -9.6	8.64	0.48	0.31-0.89	0.51	0.18
	20-40	7.9 -8.8	8.56	0.65	0.16-0.47	0.28	0.16
	40-60	7.7 -9.1	8.68	0.53	0.07-0.44	0.26	0.13
Zira	0-20	8.4-9.4	8.98	0.35	0.19-0.55	0.34	0.14
	20-40	8.6-9.4	8.94	0.29	0.22-0.43	0.28	0.02
	40-60	8.7-9.3	8.98	0.21	0.19-0.47	0.28	0.10
Overall	0-20	6.7 -9.7	8.85	0.54	0.19-3.31	0.66	0.63
	20-40	7.0 -9.8	8.88	0.60	0.16-3.28	0.59	0.62
	40-60	6.8 - 9.9	8.95	0.56	0.07-3.50	0.65	0.70

from 0.19 to 3.31, 0.16 to 3.28 and 0.07 to 3.50 dS m^{-1} with mean values of 0.66, 0.59 and 0.65 in 0-20, 20-40 and 40-60 cm depth layers of soils, respectively. Saline soils have been found in Khuian Sarwar, Fazilka and Ferozepur blocks of this district. Highest range of EC was found in soils of Khuian Sarwar block, *i.e.*, 0.25 to 3.31 dS m^{-1}, mean value of 1.42 dS m^{-1} in 0-20 cm, 0.20 to 3.27 dS m^{-1}, mean value of 1.33 dS m^{-}1in 20-40 cm and 0.17 to 3.50 dS m^{-1}, mean value of 1.41 dS m^{-1} in 40-60 cm depth layers.

Table 6.34: Range and mean values of organic carbon content of soil samples

Name of Block	**Depth(cm)**	**Organic Carbon (%)**		
		Range	**Mean**	**S.D.**
Mamdot	0 - 20	0.32 -1.27	0.902	0.340
	20 - 40	0.11 -1.04	0.648	0.355
	40 - 60	0.21 -1.08	0.592	0.384
Guru har sahai	0 - 20	0.20 - 0.50	0.37	0.116
	20 - 40	0.09 - 0.41	0.25	0.133
	40 - 60	0.14 - 0.83	0.356	0.257
Jalalabad	0 - 20	0.07 - 0.18	0.144	0.039
	20 - 40	0.11 - 0.45	0.21	0.123
	40 - 60	0.26 - 0.48	0.388	0.186
Abohar	0 - 20	0.09 - 0.66	0.28	0.205
	20 - 40	0.11 - 0.38	0.224	0.089
	40 - 60	0.09 - 0.51	0.256	0.174
Khuian Sarwar	0 - 20	0.29 -0.63	0.43	0.134
	20 - 40	0.12 -0.63	0.326	0.232
	40 - 60	0.12 - 0.68	0.348	0.237
Fazilka	0 - 20	0.27 - 0.47	0.372	0.071
	20 - 40	0.17 - 0.38	0.242	0.077
	40 - 60	0.12 - 0.47	0.208	0.132
Ghall khurd	0 - 20	0.35 - 0.99	0.678	0.243
	20 - 40	0.15 - 0.42	0.236	0.097
	40 - 60	0.11 - 0.29	0.21	0.078
Ferozepur	0 - 20	0.08 - 0.72	0.398	0.271
	20 - 40	0.09 - 0.81	0.526	0.284
	40 - 60	0.08 - 0.71	0.432	0.226
Makhu	0 - 20	0.29- 1.17	0.820	0.152
	20 - 40	0.14-0.59	0.460	0.082
	40 - 60	0.06 -1.02	0.336	0.075
Zira	0 - 20	0.20- 0.60	0.358	0.145
	20 - 40	0.14-0.20	0.166	0.023
	40 - 60	0.11 -0.24	0.156	0.047
Overall	0 - 20	0.07 -1.27	0.498	0.318
	20 - 40	0.09 -1.08	0.340	0.260
	40 - 60	0.06 -1.08	0.315	0.251

Organic carbon content of depth-wise soil samples of different blocks of Ferozepur district is shown in Table 6.34. Organic carbon content varied from 0.07 to 1.27, 0.09 to 1.08 and 0.06 to 1.08 per cent in 0-20,20-40 and 40-60 cm depths of soils with a mean value of 0.50, 0.34 and 0.32 per cent, respectively in all the blocks of Ferozepur district.

Soil samples were also analysed for available P and K (Table 6.35) up to a depth of 60 cm. Available P varied from 1.8 to 54.6, 1.8 to 46.0

Table 6.35: Range and mean values of available P and K contents of soil samples

Name of Block	Depth(cm)	Available P (mg kg^{-1})			Available K (mg kg^{-1})		
		Range	Mean	S.D.	Range	Mean	S.D.
Mamdot	0 - 20	5.4 - 34.9	20.68	9.896	97.5 - 490	165.1	162.3
	20 - 40	2.7 - 25.1	13.00	8.376	95 - 480	232.1	159.9
	40 - 60	4.5 - 14.2	9.12	4.362	60 - 415	207.14	137.6
Guru har sahai	0 - 20	1.8 - 48.9	13.98	17.678	37.5 - 450	255.0	171.3
	20 - 40	2.7 - 32.3	11.40	10.755	62.5 - 315	171.7	109.3
	40 - 60	2.7 - 27.4	12.06	9.376	62.5 - 325	184.6	133
Jalalabad	0 - 20	6.4 - 16.3	10.46	3.559	120 - 320	219.2	80.4
	20 - 40	3.6 - 14.2	7.00	3.711	117.5 - 305	198.2	70.2
	40 - 60	3.6 - 18.2	5.42	1.542	135 - 290	191.4	62.8
Abohar	0 - 20	6.4 - 18.4	11.48	4.09	125 - 506.3	317.8	157.9
	20 - 40	2.7 - 18.4	10.04	6.405	127.5 - 450	274.6	140.8
	40 - 60	1.8 - 6.3	7.10	5.449	70 - 475	237.5	167.5
Khuian sarwar	0 - 20	2.7 - 6.3	8.82	5.66	80 - 383.5	236.5	110.1
	20 - 40	1.8 - 9.2	4.92	3.12	117.5 - 331.2	225.8	95.8
	40 - 60	1.8 - 16.3	7.54	6.339	107.5-406.3	253.9	135.4
Fazilka	0 - 20	3.6 - 22.8	9.86	6.83	45 - 192.5	126.8	56.3
	20 - 40	2.7- 15.2	8.18	4.533	40 -202.5	129.2	60.2
	40 - 60	1.8 - 18.4	8.66	6.032	70 - 165	112.7	46
Ghall khurd	0 - 20	2.7- 11.2	7.74	2.96	55 - 117.5	85.7	22.3
	20 - 40	1.8 - 7.3	5.46	2.096	52 - 162.5	95.9	51.4
	40 - 60	1.8 - 8.2	3.98	2.285	45 -165	103.8	45.3
Ferozepur	0 - 20	7.3 - 18.4	12.66	3.959	100 -350	192.5	100.5
	20 - 40	8.2 - 16.3	10.02	3.164	70 -187.5	170.7	94.2
	40 - 60	10.2 - 48.9	19.14	14.95	85 - 325	178.5	95.9
Makhu	0 - 20	6.6 - 54.6	22.22	13.40	47.5 -162.5	138.0	45.0
	20 - 40	4.8 -46.0	13.96	15.49	47.5 - 237.5	120.5	61.8
	40 - 60	3.9 - 14.3	6.52	8.62	32.5 -337.5	126.5	150.0
Zira	0 - 20	3.6 - 22.8	10.10	7.40	40 - 202.5	121.7	83.1
	20 - 40	3.6 -20.5	9.06	6.358	62 -220.5	129.4	71.6
	40 - 60	2.7 - 18.4	7.48	5.594	65 - 207.5	114.2	58.4
Overall	0 - 20	1.8 -54.6	13.60	10.761	37.5 -506.3	187.9	123.9
	20 - 40	1.8 -46.0	10.42	8.922	40 - 480	167.1	105.4
	40 - 60	0.06 - 48.9	8.79	7.800	32.5 -475	160.0	110.6

and 0.06 to 48.9 mg kg^{-1} in 0-20, 20-40 and 40-60 cm depths in different blocks of Ferozepur district with a mean value of 13.60, 10.42 and 8.79 mg kg^{-1}, respectively. Further, Available K content varied from 37.5 to 506, 40 to 480 and 32.5 to 475 mg kg^{-1} in 0-20, 20-40 and 40-60 cm depths in different blocks of Ferozepur district with mean values of 188, 167 and 160 mg kg^{-1}, respectively.

Ammonium-N concentration in different blocks of Ferozepur district varied from 0.87 to

Table 6.36: Range and mean values of NH_4^+-N and NO_3^--N in soil samples

Name of Block	Depth (cm)	NH_4^+-N (mg kg^{-1})			NO_3^--N (mg kg^{-1})		
		Range	Mean	S.D.	Range	Mean	S.D.
Mamdot	0 - 20	1.51-3.59	2.31	0.838	15.7 -50.1	38.08	14.955
	20 - 40	1.35-2.61	1.91	0.456	18.95 -37.60	26.05	7.007
	40 - 60	1.23-2.51	1.87	0.477	17.25 -50.23	29.16	13.062
Guru har sahai	0 - 20	1.16 -3.10	1.82	0.829	13.25 -35.20	23.75	8.909
	20 - 40	1.21 -2.21	1.58	0.403	13.5 -24.2	19.11	4.432
	40 - 60	1.18 -2.18	1.63	0.388	18.85 -29.7	22.75	4.299
Jalalabad	0 - 20	1.54 -3.84	2.81	0.831	13.10 -38.70	24.29	0.688
	20 - 40	1.62 -3.63	2.89	0.813	11.50- 21.10	16.04	0.969
	40 - 60	1.47 -3.58	2.83	0.843	12.55 -25.0	17.65	4.826
Abohar	0 - 20	3.10 -3.85	3.53	0.301	12.25 -21.05	15.26	3.637
	20 - 40	2.93 -4.23	3.66	0.491	8.73 -26.2	15.60	6.821
	40 - 60	3.46 -4.54	3.95	0.433	7.95 -19.5	13.74	3.718
Khuian sarwar	0 - 20	3.03 -4.46	3.71	0.643	12.1 -138.5	63.32	60.84
	20 - 40	2.90 -5.11	3.90	0.860	9.0 -142.5	61.92	57.54
	40 - 60	2.96 -5.11	3.95	0.874	4.90 -125.0	57.17	59.13
Fazilka	0 - 20	0.87 -4.18	2.69	1.577	9.15 -35.90	20.09	10.329
	20 - 40	0.96 -4.48	2.76	1.525	6.90 -31.7	17.39	9.297
	40 - 60	0.91 -4.40	2.64	1.578	8.0 -39.70	21.08	12.987
Ghall khurd	0 - 20	1.12 -2.60	1.85	0.622	14.90 -50.0	29.31	13.122
	20 - 40	1.30 -3.05	2.13	0.821	14.4 -24.5	19.39	4.507
	40 - 60	1.28 -2.78	1.98	0.662	16.15 -28.5	21.05	5.437
Ferozepur	0 - 20	1.10 -2.04	1.58	0.375	1.10 -2.04	1.58	0.375
	20 - 40	1.41 -2.77	2.09	0.588	1.41 -2.77	2.09	0.588
	40 - 60	1.68 -2.17	1.90	0.175	1.68 -2.17	1.90	0.175
Makhu	0 - 20	2.48 -4.95	3.14	0.813	12.8 -50.0	30.1	11.512
	20 - 40	2.42 -2.83	2.68	0.511	4.02 -36.4	20.31	8.021
	40 - 60	2.47 -2.87	2.69	0.515	4.26 -30.4	18.3	7.093
Zira	0 - 20	2.71 -3.56	3.25	0.337	2.43 -6.45	4.04	1.52
	20 - 40	3.32 -3.51	3.39	0.088	3.16 -4.35	3.75	0.540
	40 - 60	3.32 -3.89	3.53	0.229	2.97 -5.44	4.45	0.940
Overall	0 - 20	0.87 - 4.95	2.69	1.027	3.27 -138.5	29.4	23.92
	20 - 40	0.96 -5.11	2.71	0.975	3.16 142.5	24.44	22.16
	40 - 60	0.91 -5.11	2.71	1.029	3.81 -125.0	24.13	22.23

4.95, 0.96 to 5.11 and 0.91 to 5.11 mg kg^{-1} with mean values of 2.69, 2.71 and 2.71, respectively in 0-20, 20-40 and 40-60 cm depths. Similarly, nitrate-N concentration varied from 3.3 to 138.5, 3.2 to 142.5 and 3.8 to 125 mg kg^{-1} with mean values of 29.4, 24.4 and 24.1, respectively in 0-20, 20-40 and 40-60 cm depths (Table 6.36) of soils in different blocks of Ferozepur district.

6.3.3 Hooghly

Soil sampling and analysis

Horizon-wise (0-20, 20-40 and 40-60 cm) soil samples were also collected during pre-monsoon season of 2006 from the representative sites (from where water samples collected) for their analyses for clay, sand and silt, organic carbon (OC), pH, electrical conductivity (EC), total nitrogen (TN) and NO_3-N load using standard method, to ascribe the possible causes for variations in the observed concentration of NO_3 in the water samples.

Horizon-wise (0-20, 20-40 and 40-60 cm) variation in pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), NO_3-N content, clay, sand and silt content of the 68 soil profiles were studied. It was observed that with the increase in depth pH and clay content of the soils of Hooghly district increased and that of EC, organic C, total N, NO_3-N, sand and silt contents decreased (Tables 6.37 and 6.38).

Table 6.37: Depth-wise variations in pH, EC, OC and total N content of soils

Depth	pH			EC (dSm^{-1})			OC (%)			TN (%)		
(cm)	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	4.5-7.8	6.27	0.81	0.03-0.62	0.22	0.13	0.27-1.67	0.80	0.34	0.06-0.75	0.24	0.15
20-40	5.2-7.8	6.84	0.56	0.04-0.52	0.17	0.09	0.07-1.21	0.40	0.24	0.04-0.67	0.20	0.13
40-60	5.4-8.2	6.85	0.52	0.02-0.46	0.15	0.09	0.04-0.84	0.33	0.20	0.02-0.58	0.17	0.12

Table 6.38: Depth-wise variations in NO_3-N, sand, silt and clay content of soils

Depth	NO_3-N (mg kg^{-1})			Sand (%)			Silt (%)			Clay (%)		
(cm)	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	1.20-34.75	9.08	6.41	0.8-59.2	35.02	14.54	12.0-35.6	23.40	5.83	19.6-75.2	41.58	13.43
20-40	0.09-32.10	7.87	5.81	2.1-63.2	35.67	14.68	10.0-36.0	21.24	6.16	21.3-75.9	43.09	12.97
40-60	0.05-31.25	6.36	5.00	1.1-64.5	34.80	13.90	7.9-34.0	19.44	6.30	22.6-76.1	45.75	12.64

5.3.4 Jalgaon

Soil sampling and analysis

Horizon-wise (0-20, 20-40 and 40-60 cm) soil samples were also collected during pre-monsoon season of 2006, pre and post monsoon 2007 from the representative sites (from where water samples collected) of each village for their analyses for clay, sand and silt, organic carbon (OC), pH, electrical conductivity (EC), and NO_3-N load using standard method, to ascribe the possible causes for variations in the observed concentration of NO_3 in the water samples.

Horizon-wise variation in pH and electrical conductivity (EC) of the soil was found to increase with increase in depth from surface to subsurface (Table 6.39). The organic carbon (OC) and NO_3-N content in the soil samples was found to decrease as the depth of the sampling increases from surface to sub surface (Table 6.39). The clay and silt content of the 48 soil profiles were also studied. It was observed that with the increase in depth the clay and silt contents increased (Table 6.40).

Table 6.39: Depth-wise variations in pH, EC, NO_3 and OC of soils

Depth (cm)	pH		EC (dS m^{-1})		NO_3-N (mg kg^{-1})		OC (%)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
0-20	7.50-8.50	8.04	0.124-1.360	0.506	0-11.67	2.40	0.24-0.82	0.59
20-40	7.70-8.50	8.08	0.130-1.420	0.528	0-8.81	1.96	0.29-0.71	0.50
40-60	7.60-8.50	8.13	0.137-1.470	0.551	0-9.26	1.93	0.15-0.56	0.38

Table 6.40: Depth-wise variations in sand, silt and clay content of soils

Depth (cm)	Sand (%)		Silt (%)		Clay (%)	
	Range	Mean	Range	Mean	Range	Mean
0-20	41-79.75	53.76	2.50-37.50	14.24	15.25-49.75	32.00
20-40	42.3-61.5	43.3	9.17-34.8	16.1	28.6-60.7	59.4
40-60	35.4-68.7	46.2	15.2-21.6	17.3	26.8-49.7	63.5

6.3.5 Coimbatore district

Soil sampling and analysis

Horizon-wise (0-20, 20-40 and 40-60 cm) soil samples were also collected during pre-monsoon season of 2006 from the representative sites (from where water samples were collected) for their analyses for pH, electrical conductivity (EC), Organic carbon (OC), total nitrogen, NO_3-N and NH_4-N content using standard procedures, to ascribe the possible causes for variations in the observed concentration of NO_3 in the water samples.

There was a slight variation in pH, electrical conductivity, organic carbon, total nitrogen, NO_3-N and NH_4-N content of the soil samples. It was inferred that with the increase in depth of soil profile, pH and EC of the soil increased and that of EC, organic C, total N, NO_3-N and NH_4-N content were decreased (Tables 6.41 and 6.42).

5.3.6 Hoshangabad district

Soil sampling and analysis

Depth-wise (0-15, 15-30 and 30-45 cm) soil samples were also collected during pre-

Table 6.41: Depth-wise variations in pH, EC and organic carbon content of soils

Depth (cm)	pH			EC (dSm^{-1})			OC (%)		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	7.54-8.52	8.02	0.21	0.01-1.48	0.34	0.27	0.39-1.23	0.87	0.24
20-40	7.56-8.64	8.01	0.24	0.01-1.25	0.32	0.23	0.34-1.17	0.76	0.22
40-60	7.36-8.61	8.05	0.23	0.01-1.57	0.37	0.3	0.25-1.01	0.69	0.21

Table 6.42: Depth-wise variations in total N, NO_3-N and NH_4-N content of soils

Depth (cm)	Total N (%)			NO_3-N (mg kg^{-1})			NH_4-N (mg kg^{-1})		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
0-20	0.17-0.54	0.37	0.097	2.44-38.33	8.81	7.16	0.00-2.24	0.84	0.52
20-40	0.15-0.51	0.34	0.09	3.27-35.46	8.77	6.59	0.03-2.69	0.87	0.61
40-60	0.11-0.44	0.31	0.1	3.28-16.93	7.58	4.15	0.01-2.39	0.79	0.58

monsoon season of 2006 and 2007 from the representative sites (from where water samples were collected) for their analyses for pH, electrical conductivity (EC), Organic carbon (OC), total nitrogen, NO_3-N and NH_4-N content using standard procedures to ascribe the possible causes for variations in the observed concentration of NO_3 in the water samples.

There was no significant variation in pH of the soils with depth. Barring electrical conductivity, all other properties showed a decreasing trend with depth (Table 6.43 and 6.44). Organic carbon, Olsen-P, NO_3-N, NH_4-N and total N content of the soil decreased with depth signifying no substantial leaching of nitrate through soil profile. However, there was significant variability within soils with regards to all the parameters studied. For example, EC, OC, NO_3-N and total N content of soil were as high as 1.64 dS m^{-1}, 1.61%, 35.6 mg kg^{-1} soil and 870 mg kg^{-1} soil, respectively. Apart from variability among different soil samples, no significant accumulation of nitrate or any other forms of N was recorded in any soil even in areas recording high nitrate pollution in groundwater.

6.4 Vulnerability of groundwater to nitrate contamination

The occurrence of nitrate in groundwater beneath agricultural systems was examined by the factors influencing aquifer vulnerability to nitrate contamination and by characterizing the geographic distribution of groundwater contamination by nitrate. Aquifers and individual wells can be contaminated by substantially different processes. Agricultural chemicals can

Table 6.43: Depth-wise variations in pH, EC, OC and total N content of soils

Depth (cm)	pH		EC (dSm^{-1})		OC (%)		Olsen-P, mg kg^{-1}	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
0-15	6.3-8.1	7.7	0.17-1.64	0.43	0.43-1.61	0.69	3.97-11.96	7.85
15-30	6.4-7.9	7.4	0.32-1.35	0.52	0.35-1.24	0.52	3.12-9.56	5.97
30-45	6.3-8.0	7.8	0.43-0.89	0.51	0.23-0.97	0.48	3.23-8.79	5.23

Table6.44 : Depth-wise variations in NH_4-N, NO_3-N and total N in soils

Depth (cm)	NH_4-N, mg kg^{-1}		NO_3-N, mg kg^{-1}		Total N,%	
	Range	Mean	Range	Mean	Range	Mean
0-15	7.1-19.5	14.7	19.0-33.5	27.4	0.067-0.087	0.072
15-30	7.9-17.6	12.5	22.2-35.6	25.2	0.065-0.082	0.069
30-45	6.4-15.8	12.1	23.4-32.1	24.6	0.062-0.078	0.065

also contaminate improperly constructed wells without appreciably affecting the aquifer.

Specific vulnerability to source of nitrogen and intrinsic features of hydrologic system are principles upon which groundwater vulnerability may be estimated. Specific vulnerability to agricultural system is a function of contaminant factors such as the quantity, rate, timing, and methods of nitrogen application, irrigations, and other agriculture management characteristics. Intrinsic susceptibility is a function of hydro-geologic factors such as proximity of an aquifer to the land surface, hydrologic properties of soil, and the amount, timing, and location of aquifer recharge. Attempts have been made to collate nitrate loadings in ground waters with these factors to identify the principles which impart vulnerability to specified aquifers in the target districts.

6.4.1 West Godavari

Although the NO_3-N load in groundwater samples collected from West Godavari district of Andhra Pradesh was well below of 10.mg L^{-1}, it was observed that the NO_3-N load in groundwater samples increased with increasing rate of fertilizers application, contents of organic C, available nitrogen, NO_3-N and sand content of the soil profiles; but decreased with increasing depth of sampling aquifers and clay content of the soils. It was further observed that such load was higher in areas where shallow rooted crops were grown. As rice is a shallow rooted crop, the concentration of NO_3 was found to be high in groundwater in areas where lowland rice (double rice area particularly) is cultivated *vis-a-vis* sugarcane (Figs. 6.25 to 6.28).

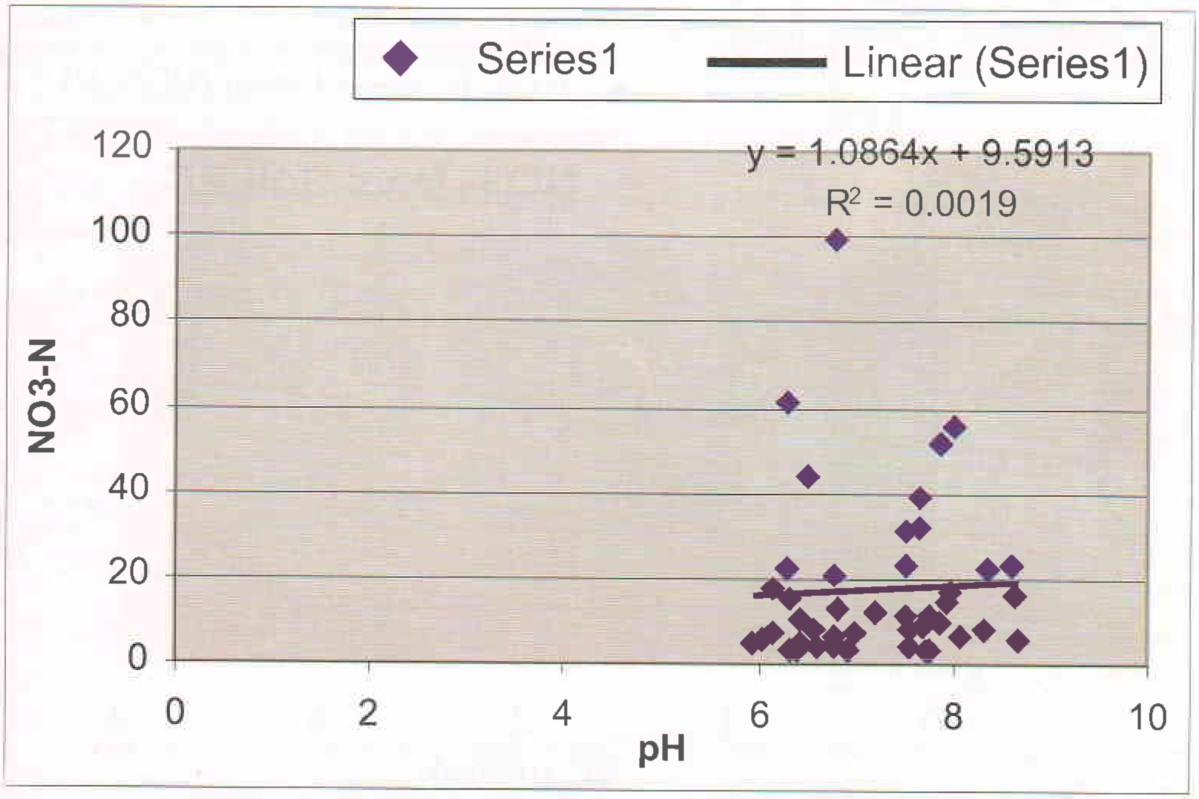


Fig. 6.25: Relation between soil pH and nitrate in groundwater

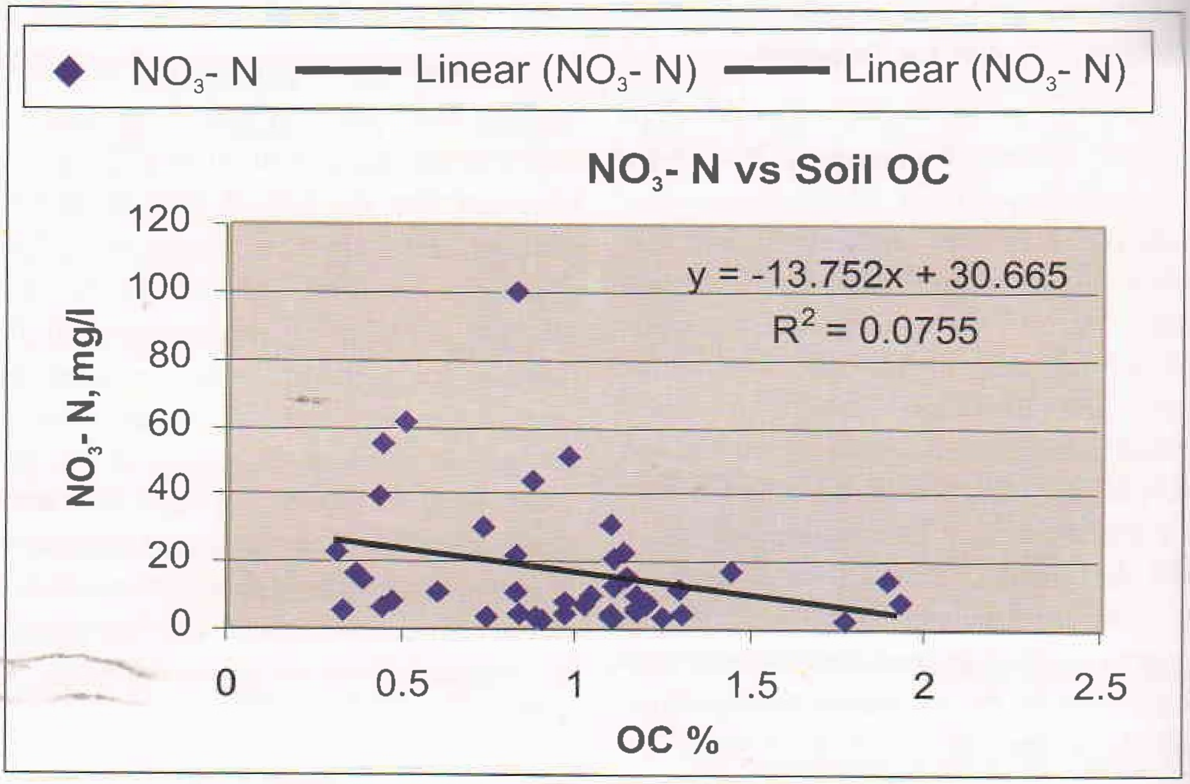


Fig. 6.26: Relation between soil OC and nitrate in groundwater

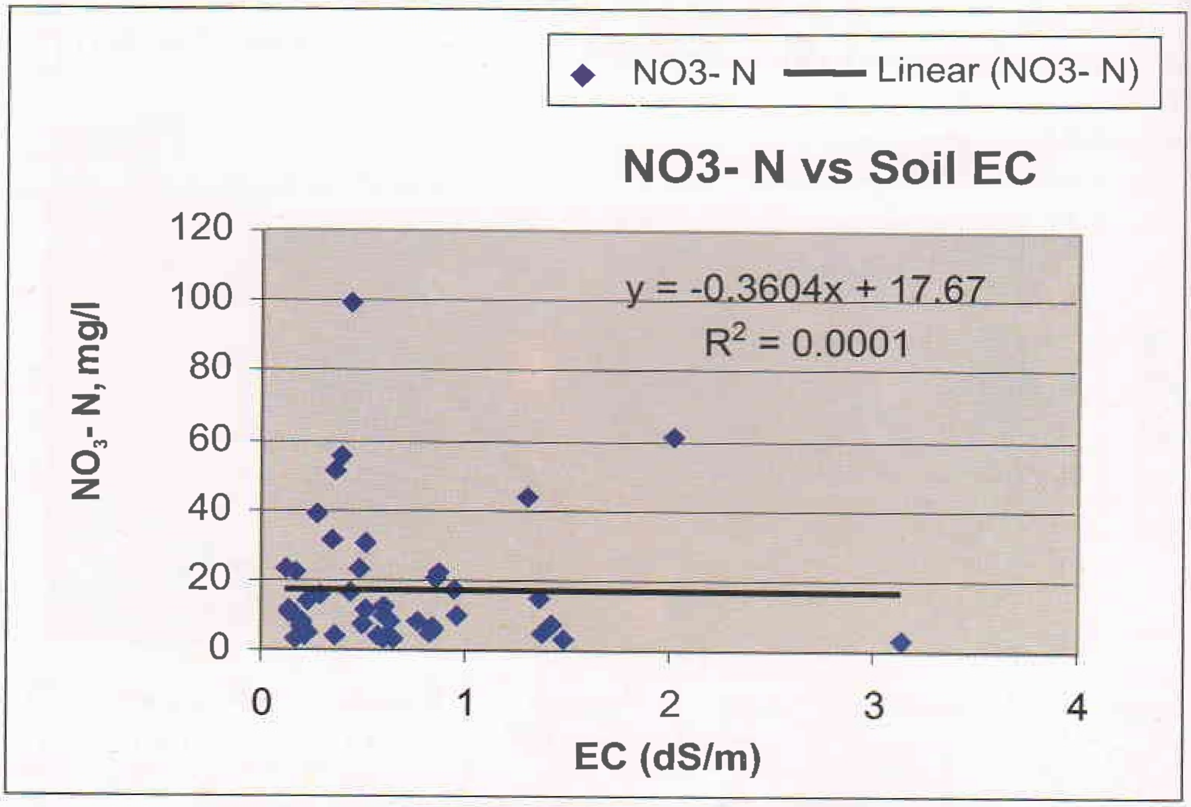


Fig. 6.27: Relation between soil EC and nitrate in groundwater

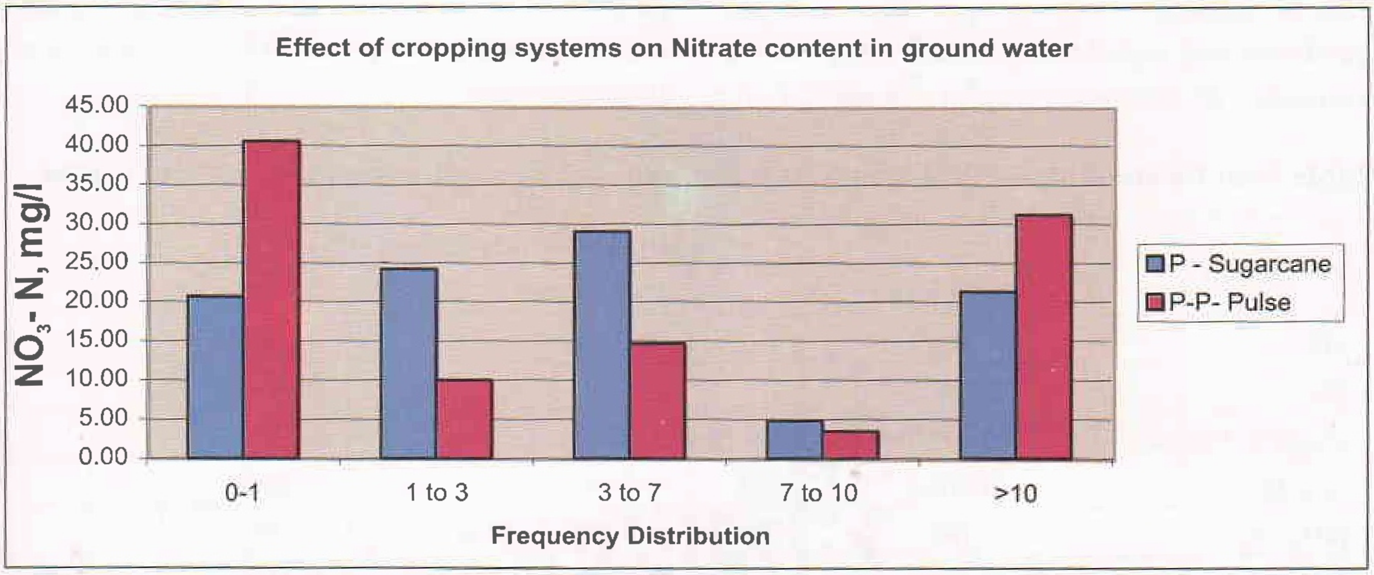


Fig. 6.28: Relation between cropping system and nitrate in groundwater

6.4.2 Ferozepur

To study the relationship of NO_3-N with different parameters of irrigation water, correlation coefficients were worked out for all three samplings (Table 6.45). NitrateN had significant negative relationship with depth of tube well, water table of the area and residual sodium carbonate (RSC), while a significant positive relationship was observed with EC, calcium + magnesium and sodium content of irrigation waters. In second and third samples also nitrate N had significant negative relationship with depth of tube well just like previous sampling. Nitrate N was having a significant positive relationship with EC (r =0.425*) and Ca+Mg (r = 0.329*) just like previous sampling.

Table 6.45: Relationships of NO_3-N with different parameters of irrigation water

Parameter	Correlation coefficient (r)		
	First sampling	Second sampling	Third sampling
Depth	- 0.219*	- 0.184*	- 0.147*
Water table depth	- 0.192*	0.068	- 0.203*
EC	0.408*	0.425*	0.333*
Ca^{++}+ Mg^{++}	0.412*	0.329*	0.219*
RSC	- 0.129*	- 0.086	0.056
Na^{+}	0.366*	-	0.287*
K^{+}	0.300*	-	0.341*

Correlation coefficients were worked out between NO_3-N contents of irrigation water with various parameters of soils (Table 6.46). There existed a significant negative relationship between OC, Olsen-P and clay content of soils with NO_3- -N content of irrigation water in surface 0-20 cm layer. Sand was positively correlated with upper two surface layers of soils, *i.e.*, 0-20 and 20-40 cm.

NH_4-N content of 20-40 cm layer soil was positively and significantly related with NO_3- -N contents of irrigation water. None of the parameters of 40-60cm layer soil was having any significant relationship with NO_3- -N contents of irrigation water.

Table 6.46: Relationships of NO_3--N of irrigation water with soil parameters at different depths

Parameter	Correlation coefficient (r)		
	0-20 (cm)	20-40 (cm)	40-60 (cm)
pH	0.006	0.030	0.048
EC	-0.140	-0.044	0.077
Organic Carbon	-0.342*	-0.226	-0.203
Available K	-0.062	-0.074	-0.069
NH_4^+-N	0.186	0.311*	0.256
NO_3^--N	-0.186	-0.098	-0.103
Available P	-0.293*	-0.204	0.037
Silt	-0.254	-0.339*	-0.174
Clay	-0.425*	-0.444*	-0.258
Sand	0.366*	0.447*	0.241

5.4.3 Hooghly

Although the NO_3-N load in groundwater samples collected from Hooghly district of West Bengal was well below of 10.mg L^{-1}, it was observed that the NO_3-N load in groundwater samples was increased with increasing rate of fertilizers application (r = 0.72, P = 0.01), contents of organic C (r = 0.79, P =0.01), total N (r = 0.91, P=0.01), NO_3-N (r = 0.84, P=0.01) and sand content (r = 0.29, P=0.05) of the soil profiles; but decreased with increasing depth of sampling aquifers (r = - 0.36, P=0.01) and clay content (r = -0.32, P=0.05) of the soils (Figs. 6.29 to 6.36). It was further observed that such load was higher in areas where shallow rooted crops were grown. Although rice is a shallow rooted crop, the concentration of NO_3 was found to be lowered in groundwater in areas where lowland rice (double rice area particularly) is cultivated *vis-a-vis* other upland crops.

5.4.4 Jalgaon

The NO_3-N load in groundwater samples collected from Jalgaon district of Maharashtra was not detected in water samples. Only in six samples NO_3-N was detected during pre and post monsoon 2007. Hence, overall groundwater aquifers of the target district of Jalgaon were not vulnerable to nitrate contamination at all.

5.4.5 Coimbatore

The NO_3-N content of groundwater samples collected from Coimbatore district of Tamill Nadu varied from 5.2to 9.52 mg L^{-1} with the overall mean value of 6.74 mg $L^{-1}$and it is below the critical level of 10.mg L^{-1}. The NO_3-N content of groundwater samples was correlated with water parameters (pH and EC), rate of fertilizer application, soil parameters (pH, EC, organic carbon, total N, NO_3-N and NH_4-N content) and depth of aquifers. The results showed that the NO_3-

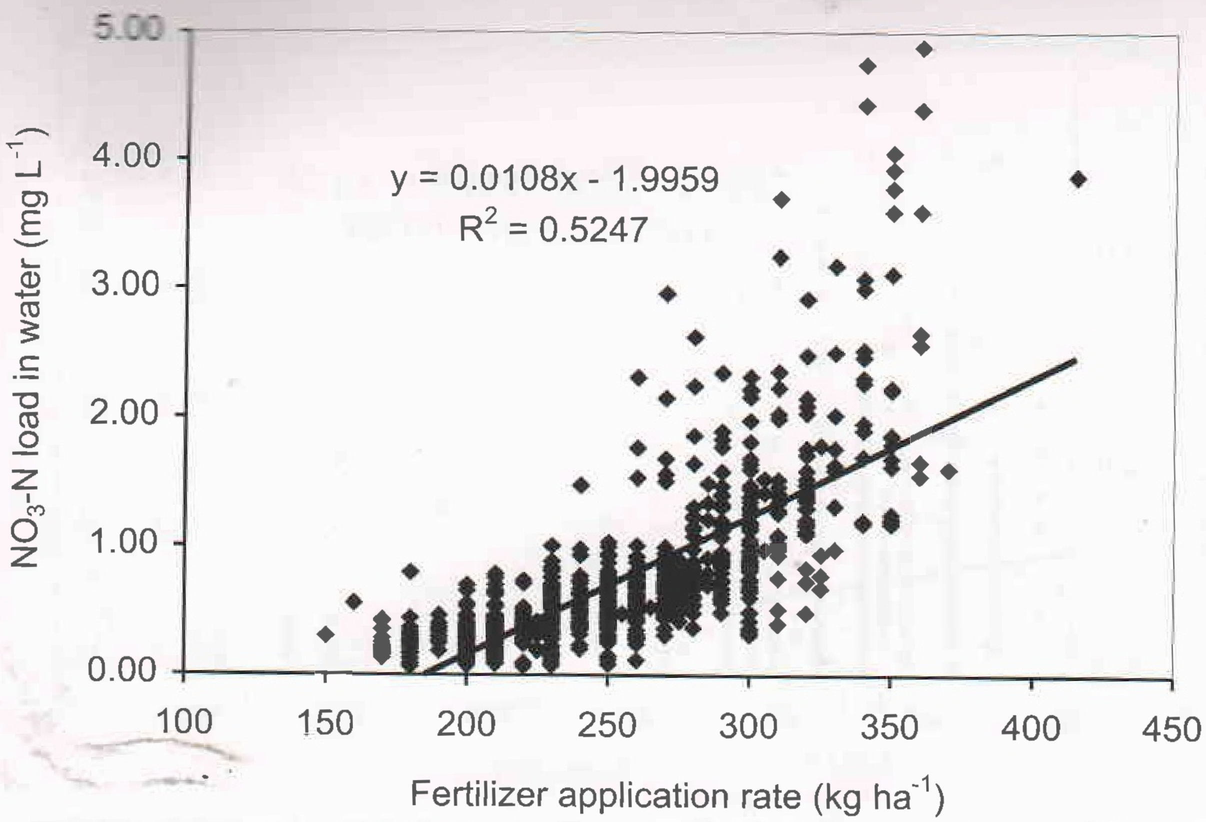


Fig 6.29: Relationships of NO_3-N load in groundwater with fertilizer application rate

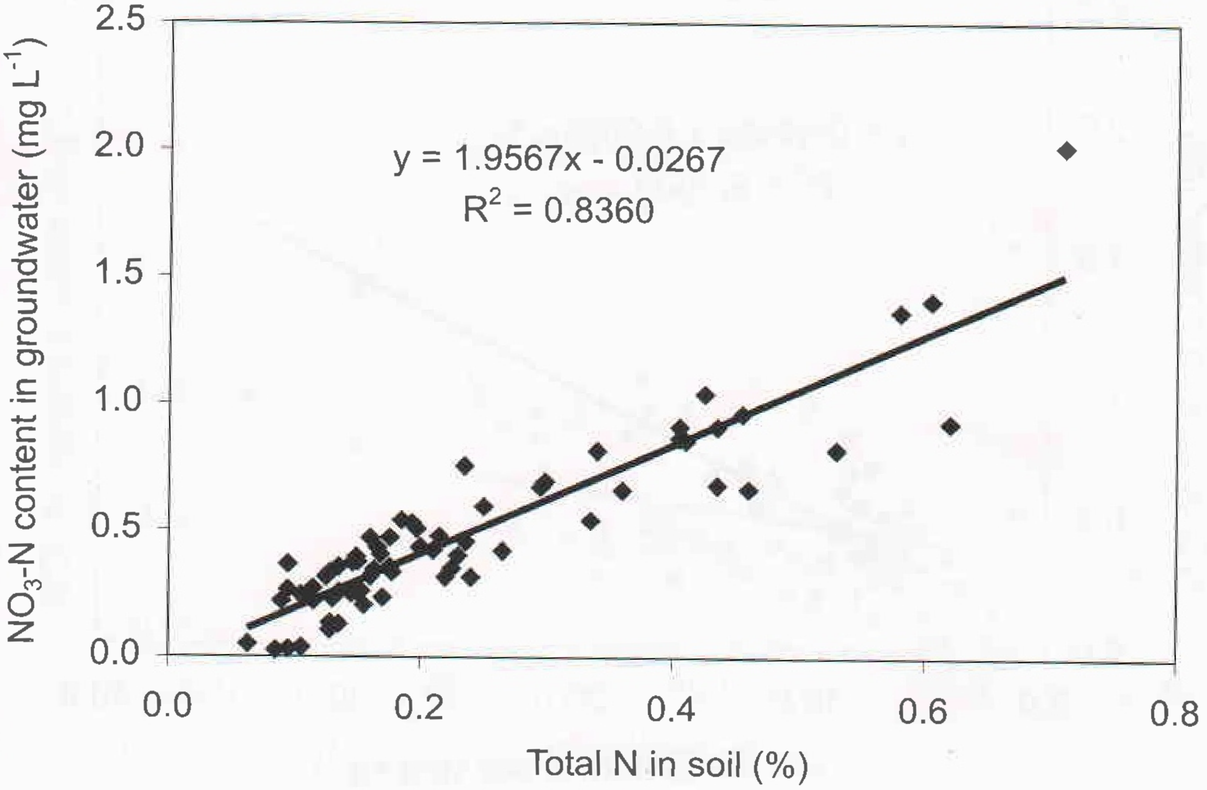


Fig 6.32: Relationships of NO_3-N load in groundwater with total N content of soils

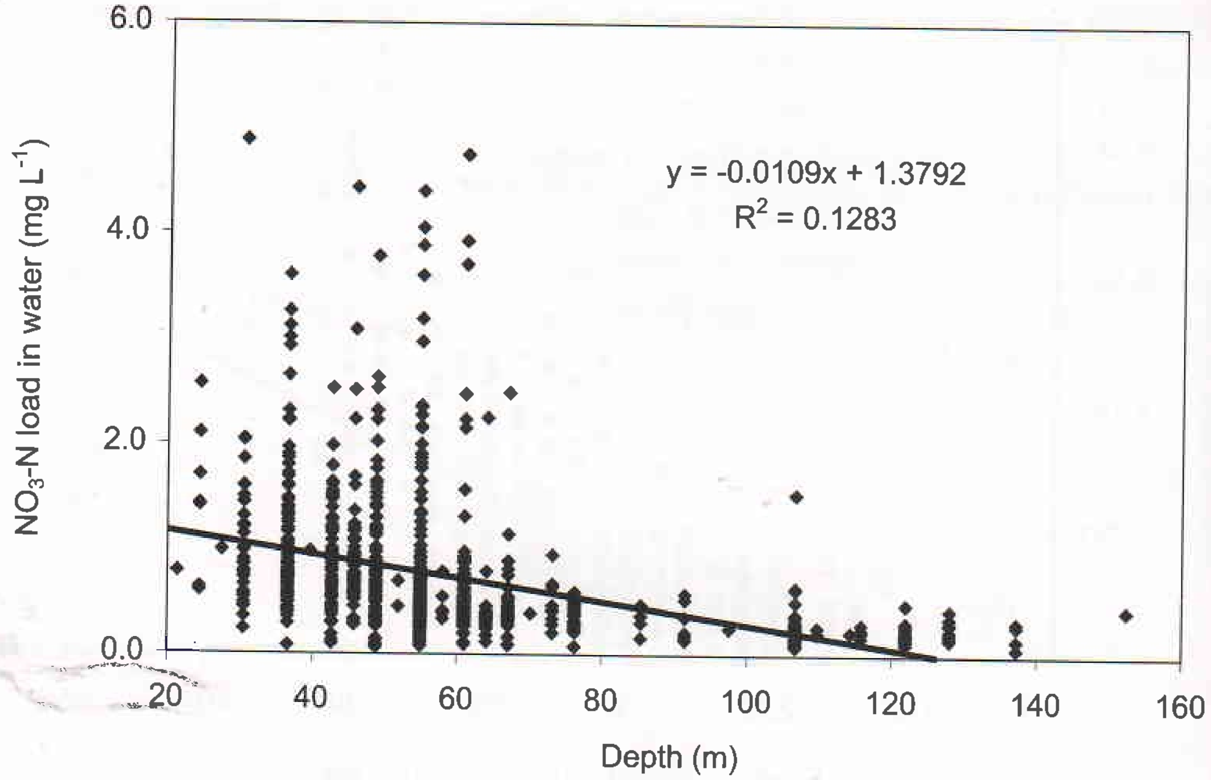


Fig.6.30: Relationships of NO_3-N load in groundwater with depth of sampling aquifers

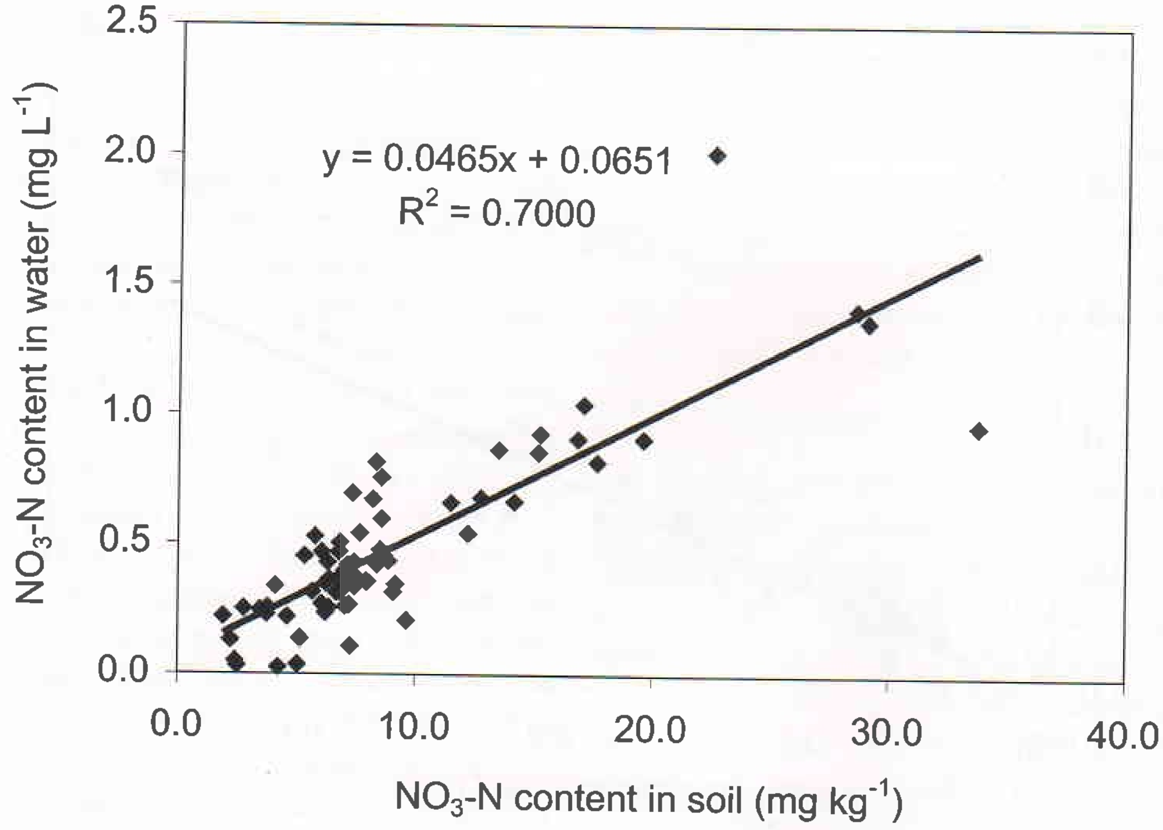


Fig 6.33: Relationships of NO_3-N load in groundwater with NO_3-N content of soils

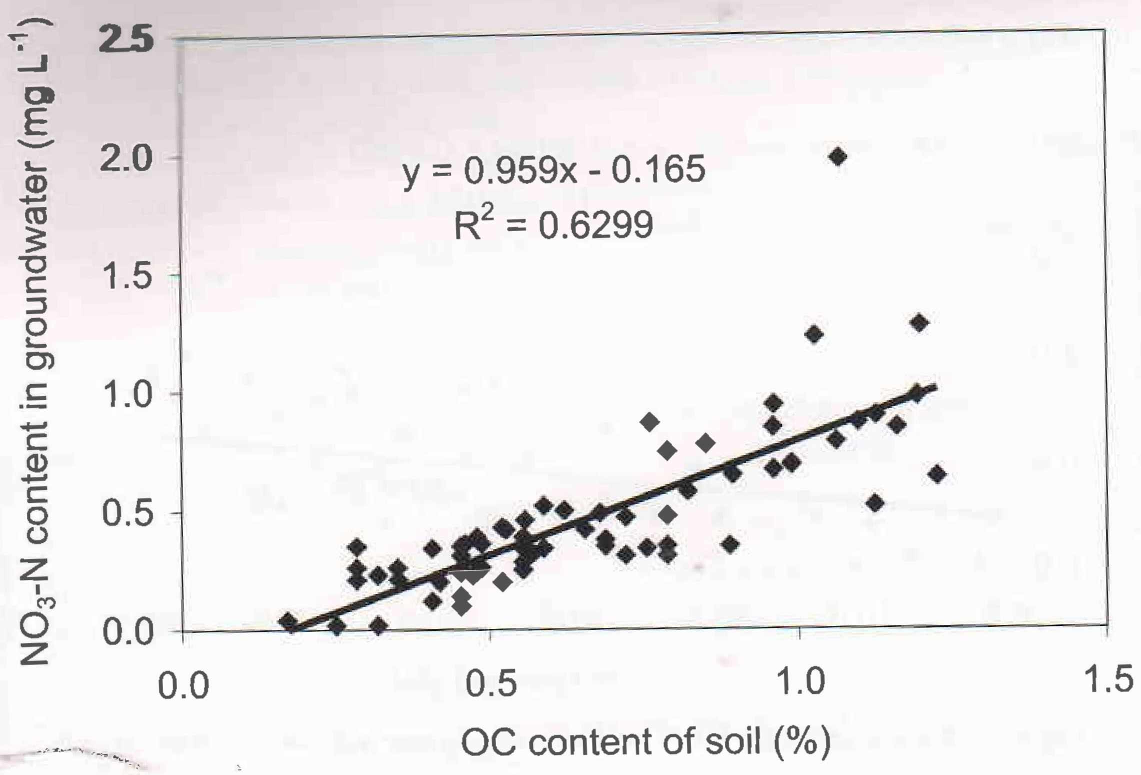


Fig 6.31: Relationships of NO$_3$-N load in groundwater with organic C content of soils

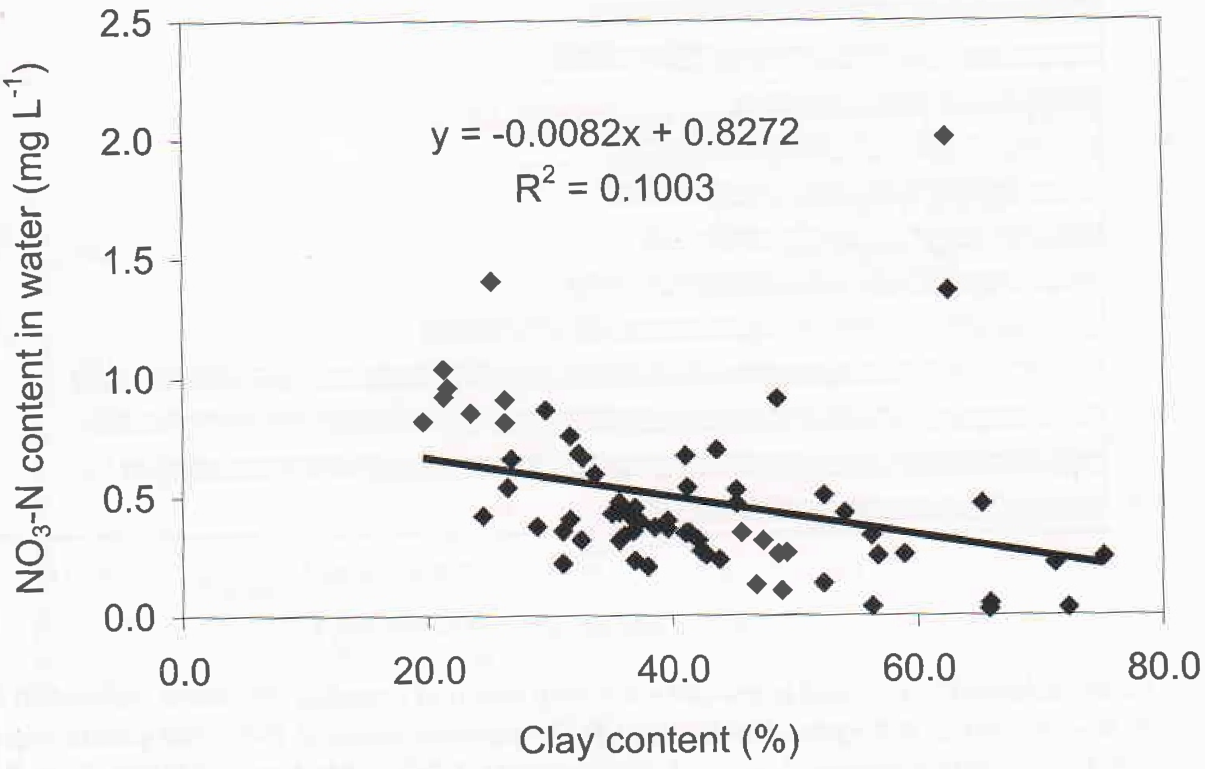


Fig 6.34: Relationships of NO$_3$-N load in groundwater with clay content of soils

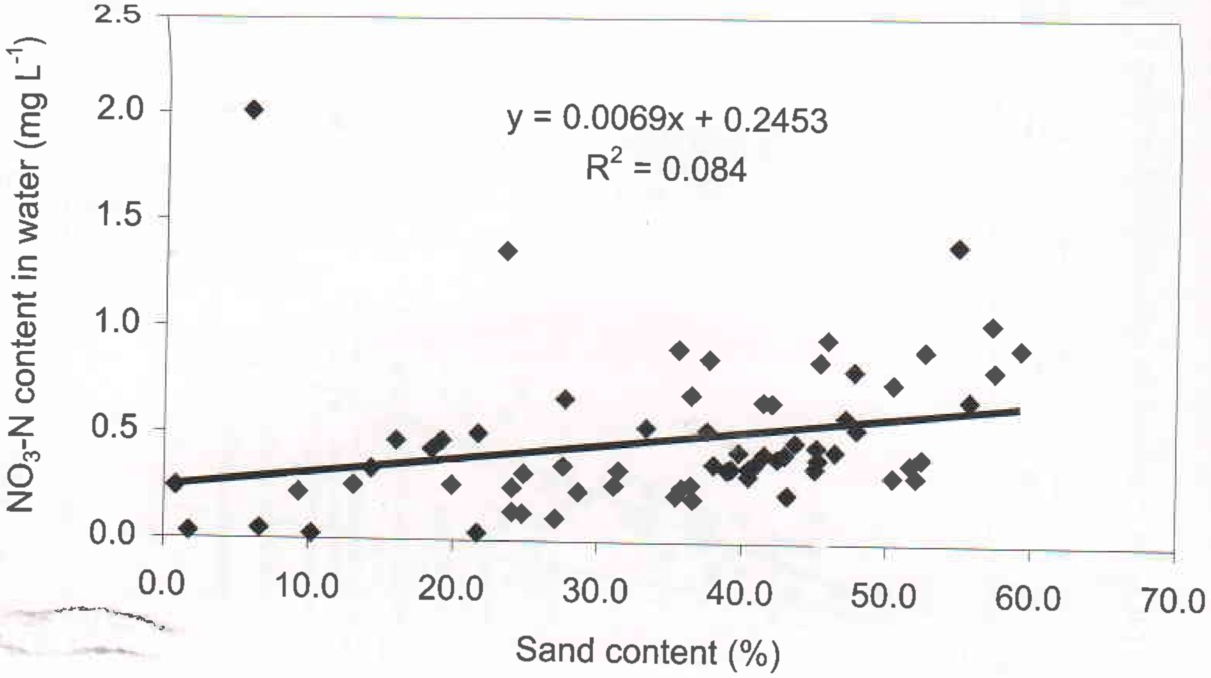


Fig. 6.35: Relationships of NO_3-N load in groundwater with sand content of soils

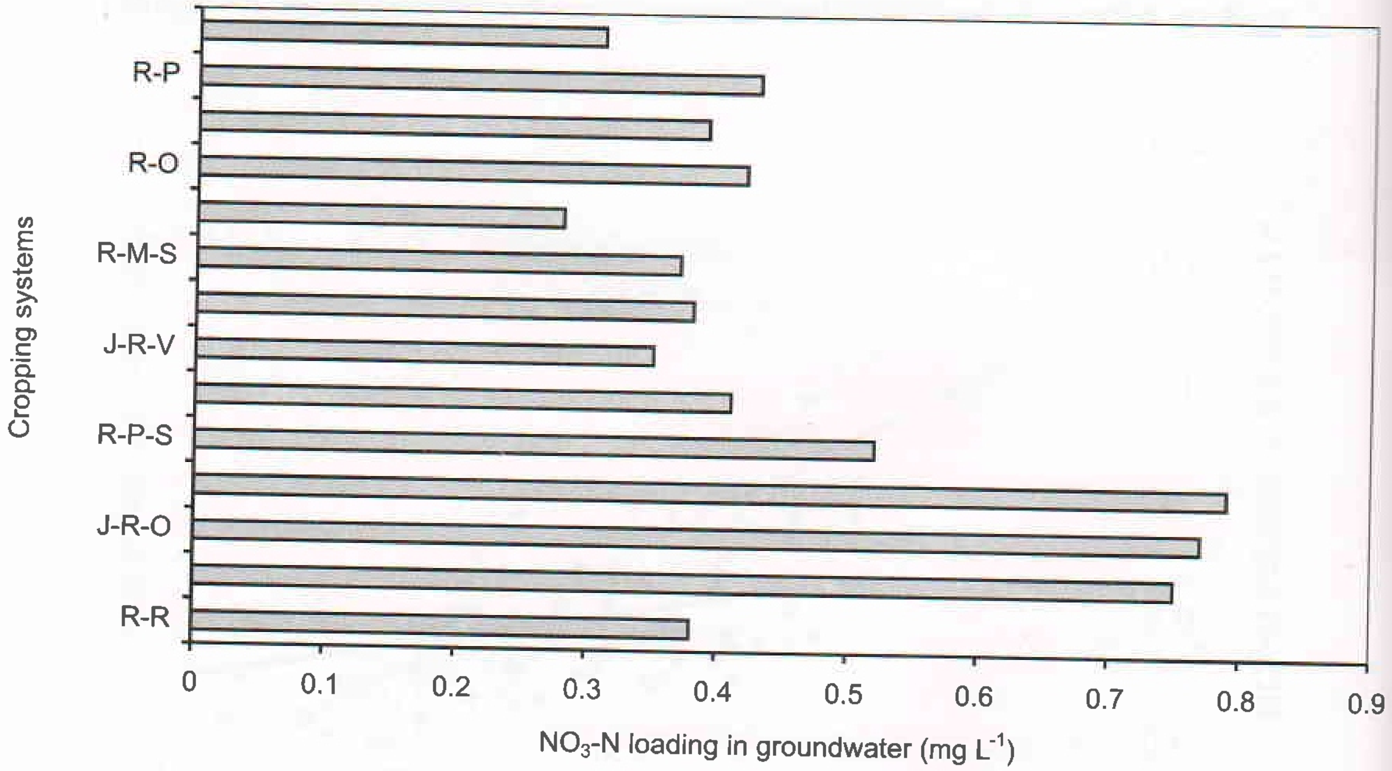


Fig. 6.36: Relationships of NO_3-N load in groundwater with different cropping systems of the studied district (R-R = rice-rice, J-R-P = jute-rice-potato, J-R-O = jute-rice-onion, R-P-V = rice-potato-vegetables, R-P-S = rice-potato-sesame, J-R-W = jute-rice-wheat, J-R-V = jute-rice-vegetables, R-M-R = rice-mustard-rice, R-M-S = rice-mustard-sesame, J-R-R = jute-rice-rice, R-O = rice-onion, R-P-R = rice-potato-rice, R-P = rice-potato, R-V = rice-vegetables.

N content in groundwater samples was positively correlated with EC of water (r = 0.16, P=0.01), rate of fertilizer application (r = 0.07, P =0.01), organic carbon (r =0.78, P=0.01), total N (r = 0.67, P=0.01), NO_3-N (r = 0.59, P =0.01) content of the soil profiles; but negatively correlated with pH of water (r = -0.43, P =0.01), EC of soil (r = -0.52, P=0.01) and depth of sampling aquifers (r = - 0.09, P=0.01) (Figs. 6.37 to 6.45).

It was further observed that the mean Nitrate-N content was higher in areas where Vegetables- Pulses and Turmeric-Pulses cropping systems were followed and lower in Rice-Rice/ Pulses cropping systems (Fig. 6.46).

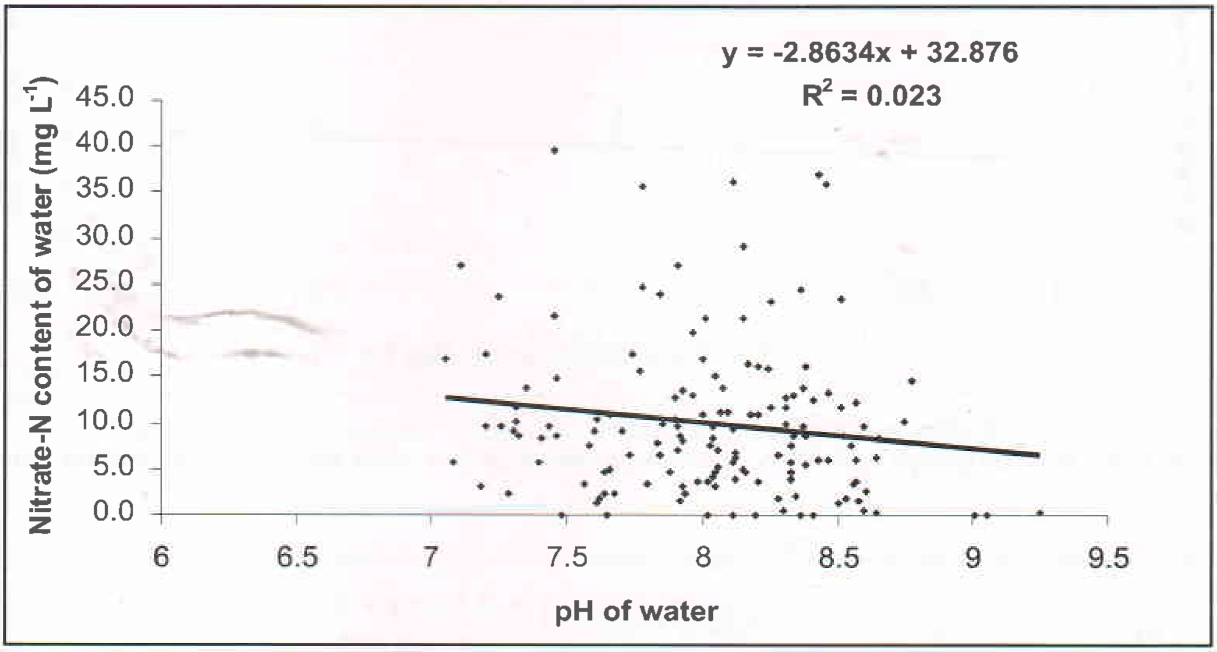


Fig. 6.37: Relationships of NO_3-N content in groundwater with pH of water

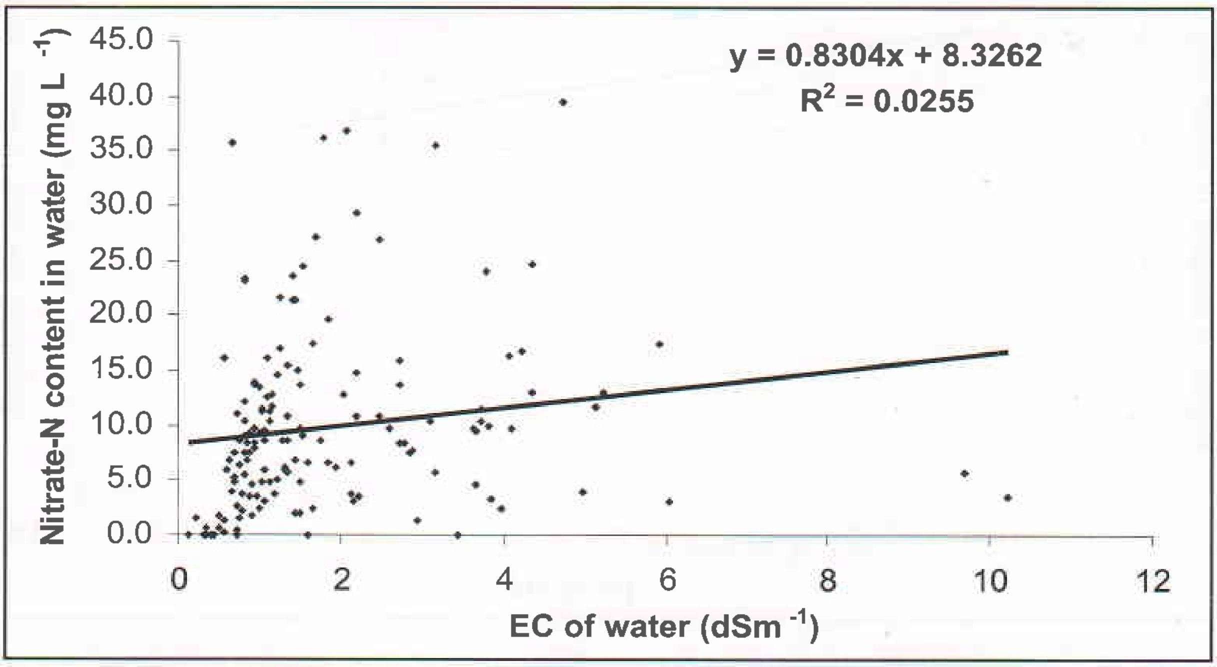


Fig. 6.38: Relationships of NO_3-N content in groundwater with EC of water

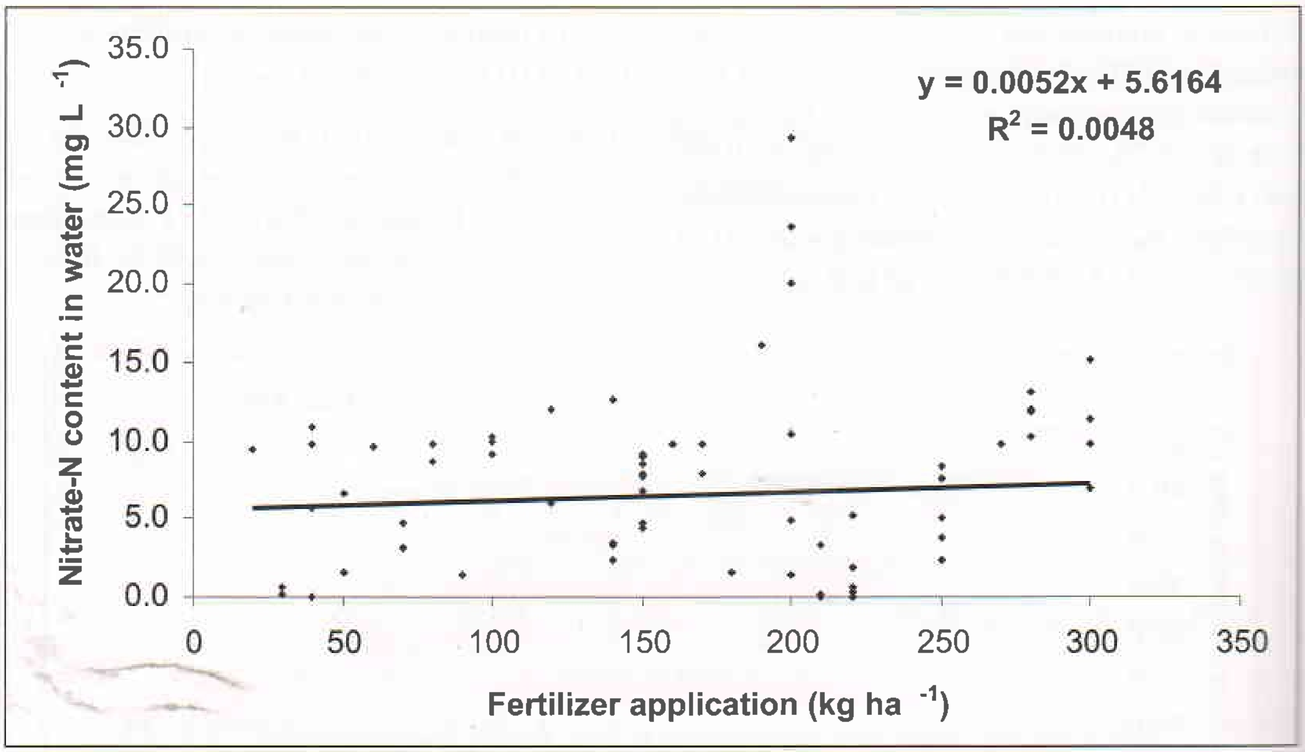


Fig. 6.39: Relationships of NO_3-N content in groundwater with fertilizer application rate

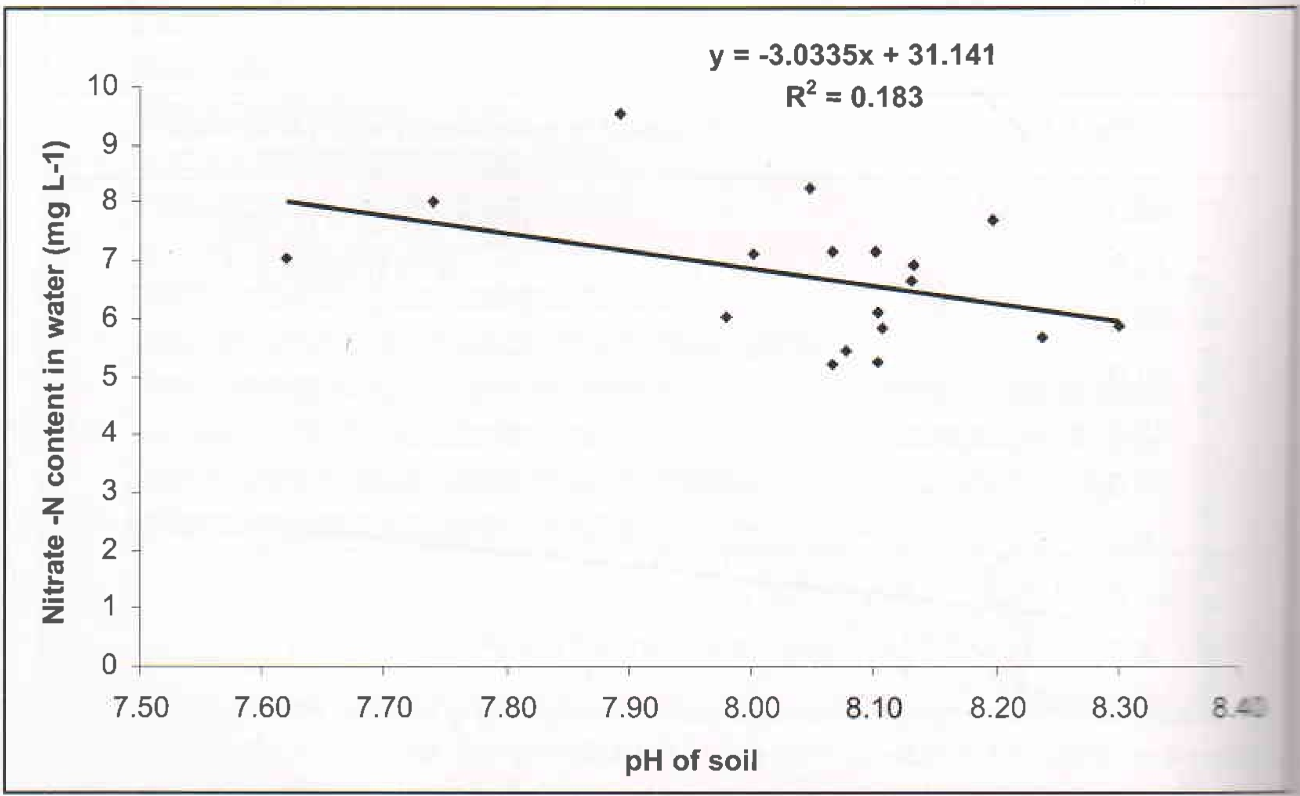


Fig. 6.40: Relationships of NO_3-N content in groundwater with pH of soil

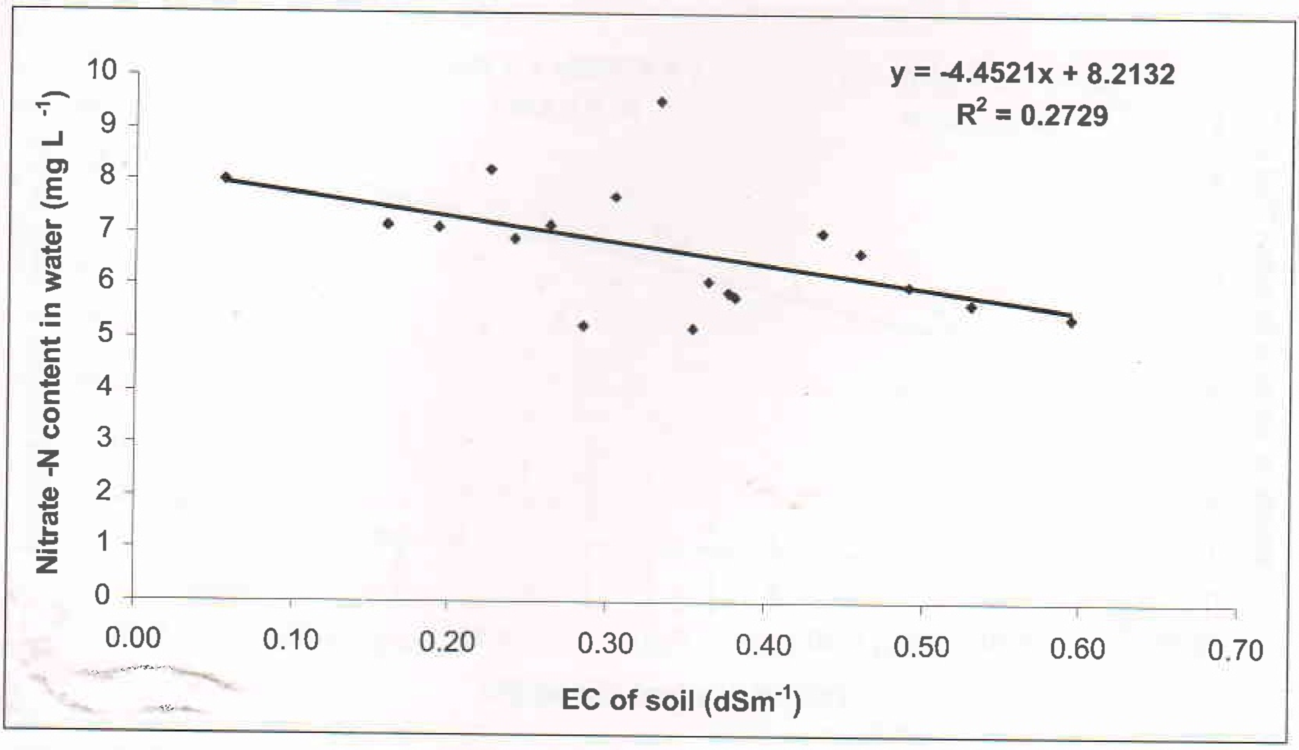


Fig. 6.41: Relationships of NO_3-N content in groundwater with EC of soil

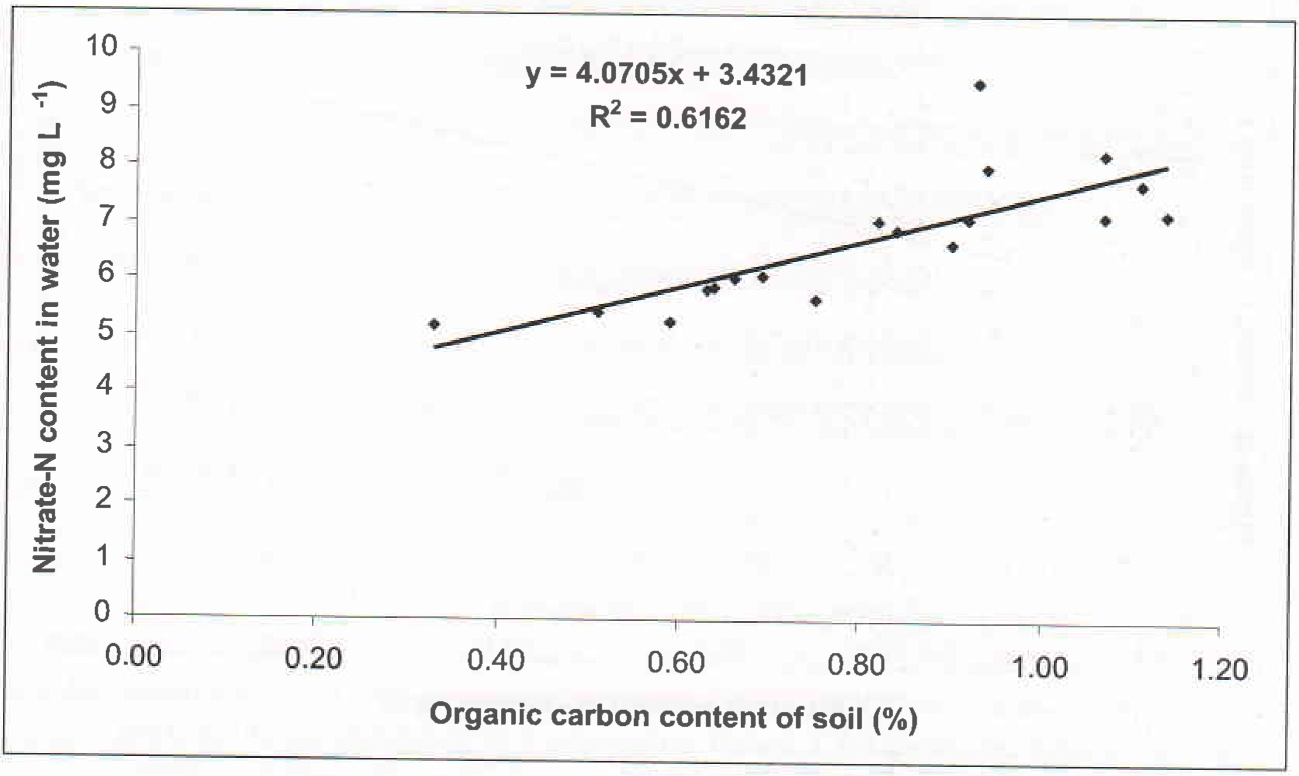


Fig. 6.42: Relationships of NO_3-N content in groundwater with organic carbon content of soil

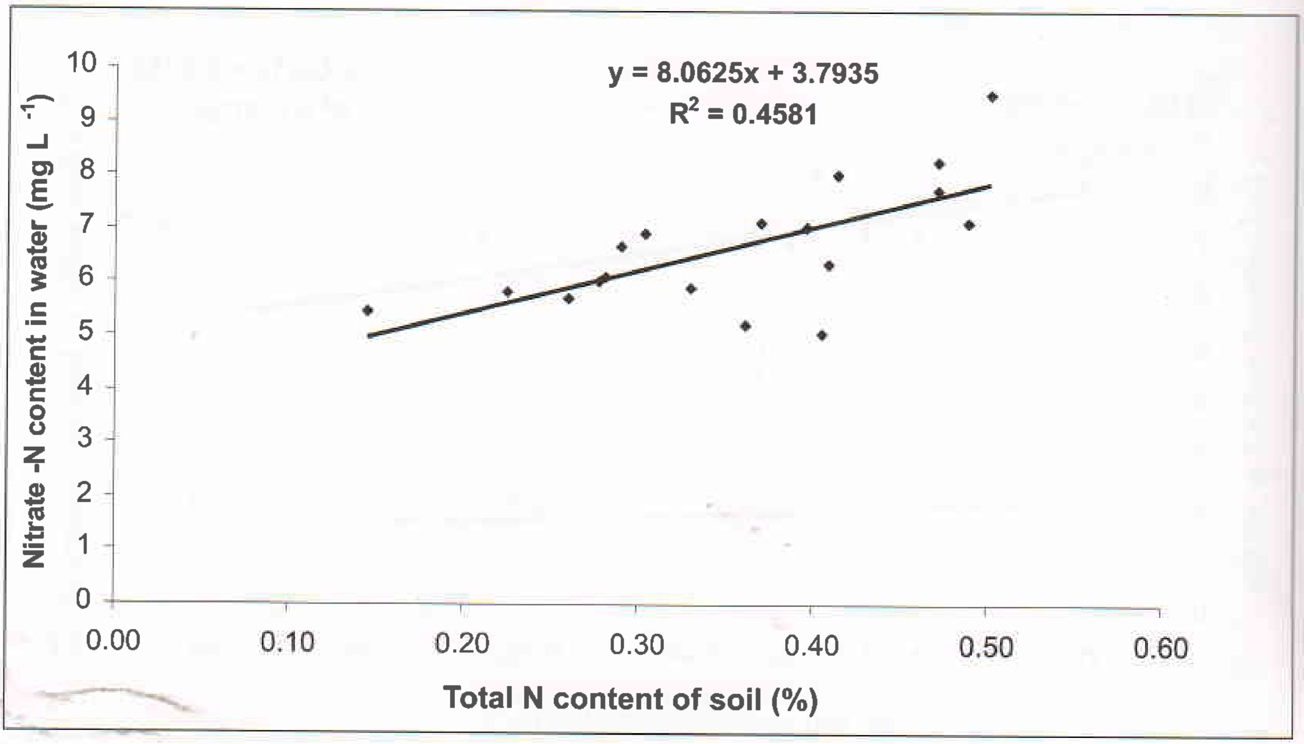


Fig. 6.43: Relationships of NO_3-N content in groundwater with total N content of soil

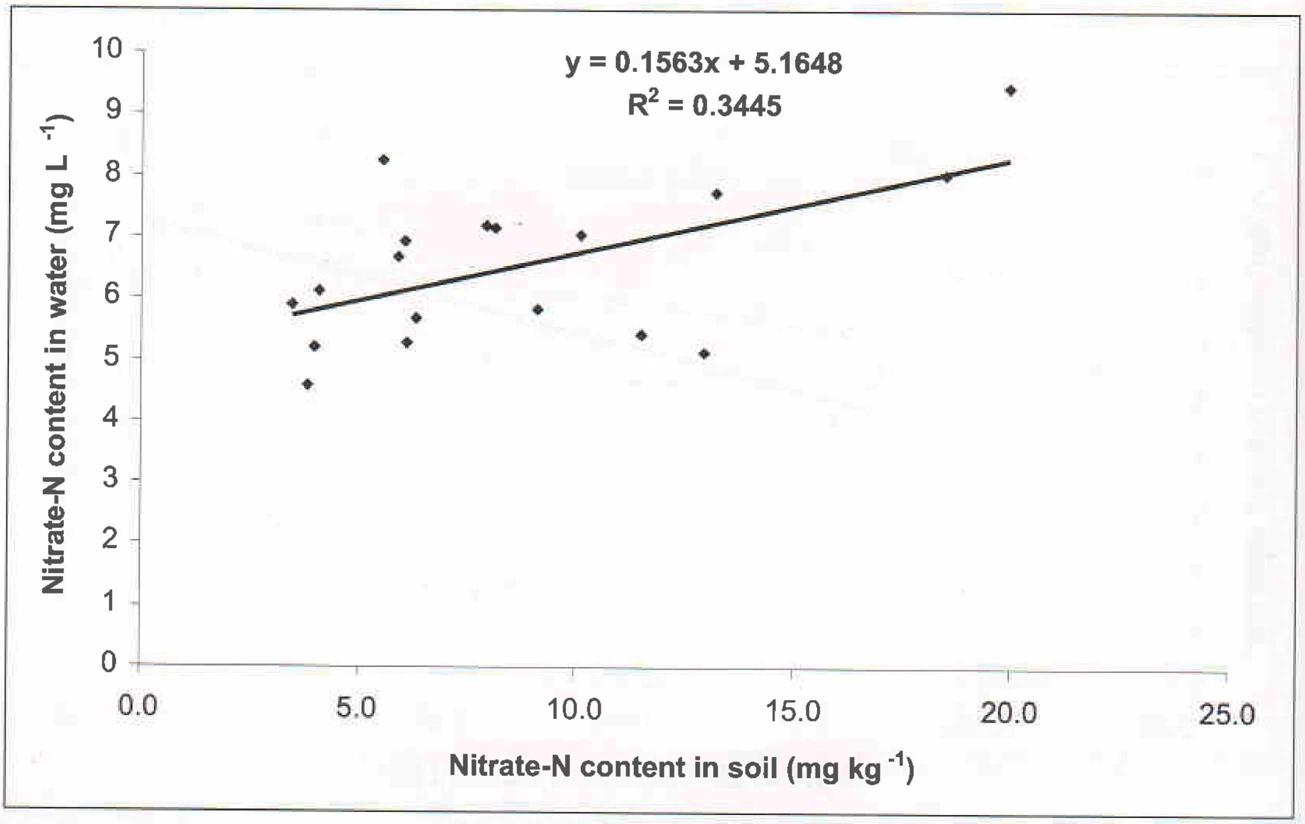


Fig. 6.44: Relationships of NO_3-N content in groundwater with NO_3-N content of soil

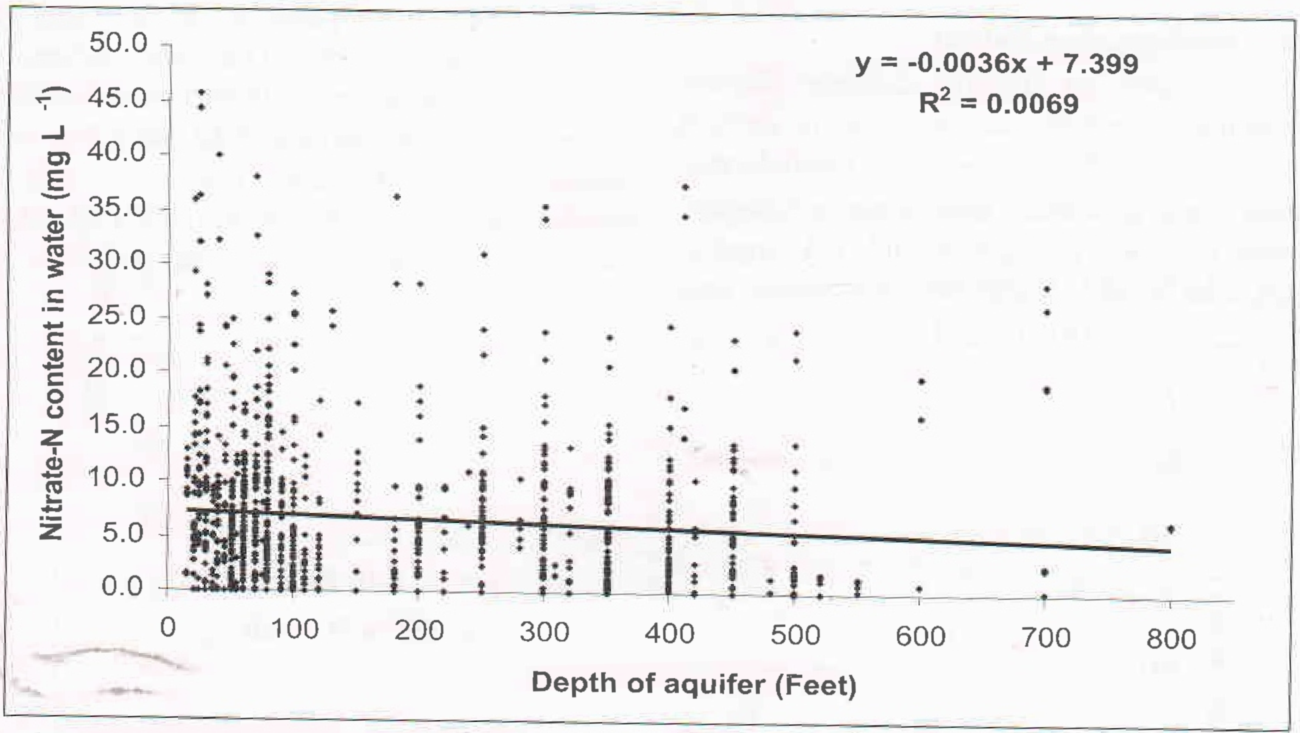


Fig. 6.45: Relationships of NO_3-N content in groundwater with depth of sampling aquifers

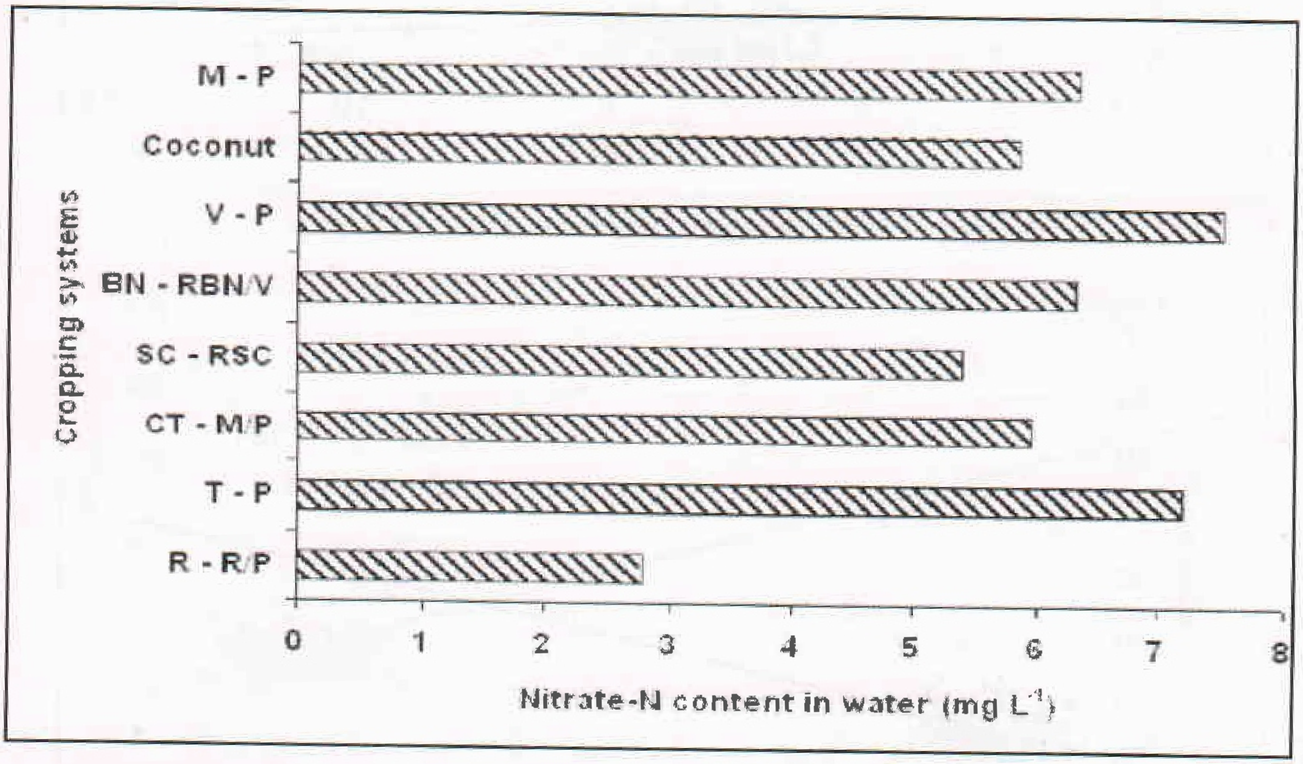


Fig. 6.46: Relationships of NO_3-N content in groundwater with different cropping systems of the Coimbatore district (R-R/P = Rice-Rice/Pulses, T-P = Turmeric Pulses, CT-M/P = Cotton - Millets/Pulses, SC-RSC = Sugarcane - Ratton Sugarcane, BN-RBN/V = Banana - Ratton Banana/Vegetables, V-P = Vegetables Pulses, Coconut, M-P = Millets Pulses)

6.4.6 Hoshangabad district

In order to identify different factors contributing to nitrate accumulation in ground waters the NO_3-N contents of groundwater samples were correlated with water parameters (pH and EC), soil parameters (pH, EC, organic carbon, total N, NO_3-N and NH4-N content), rate of fertilizer/manure application, depth of aquifers, crops/cropping systems. The relationships of nitrate in ground waters with various parameters, as represented in figures 6.47 to 6.58, were intended to understand the behaviour of interactions among different factors in making the sources of water vulnerable to nitrate pollution.

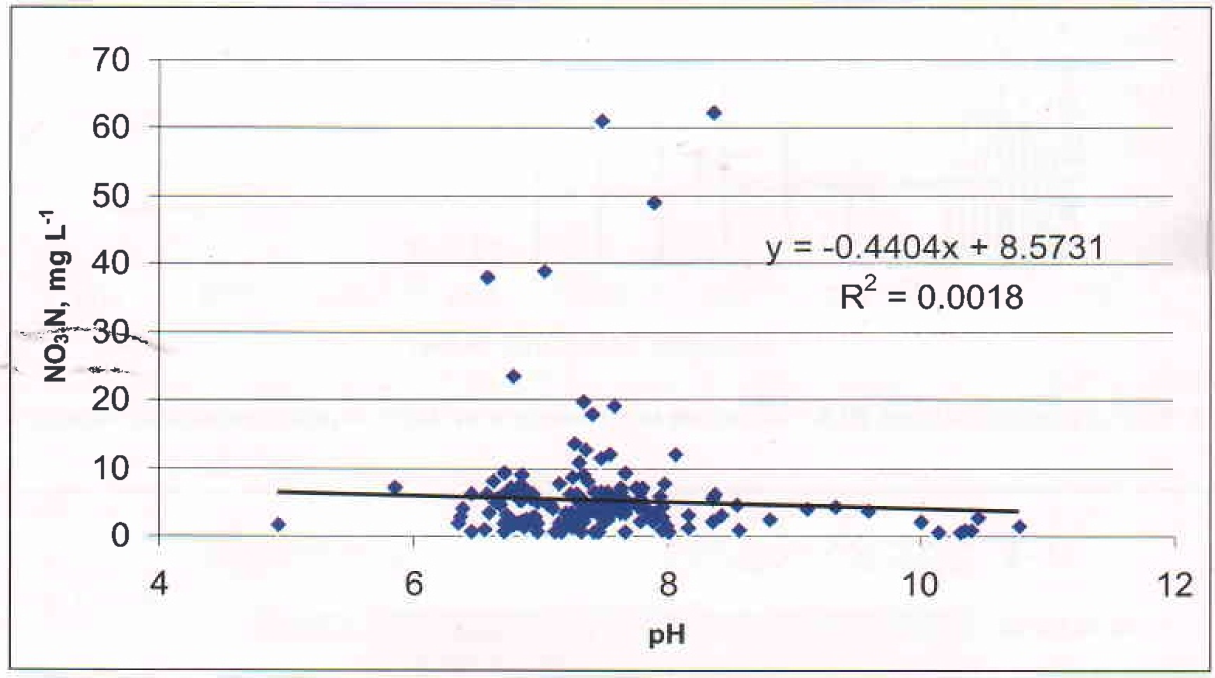


Fig.6.47: Relation between pH and nitrate in ground water

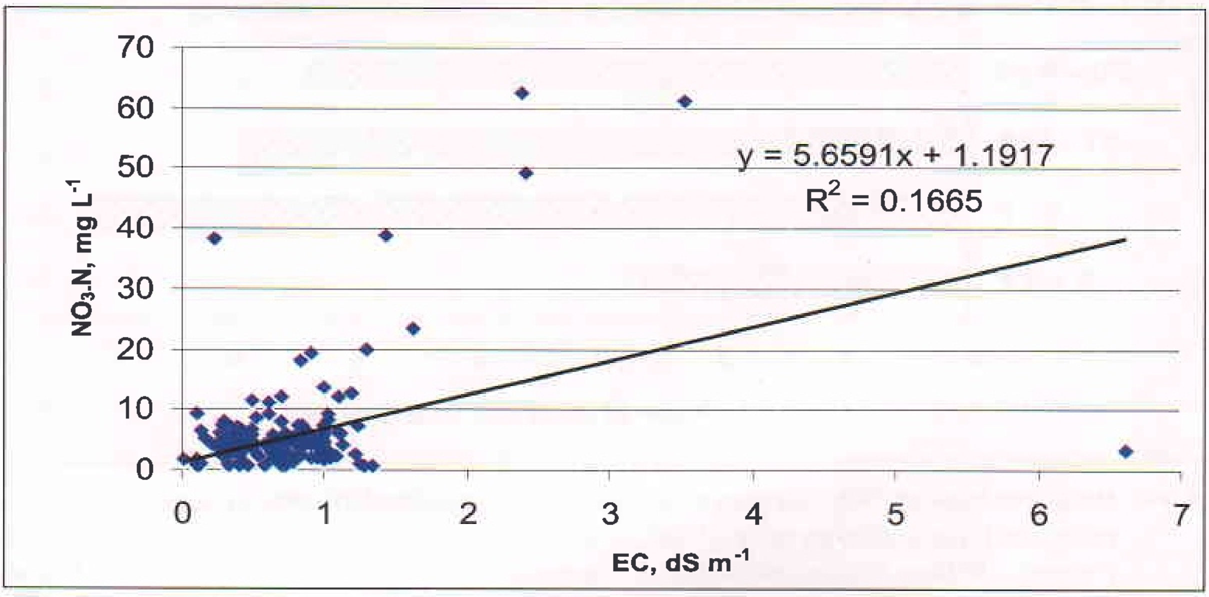


Fig.6.48: Relation between EC and nitrate in ground water

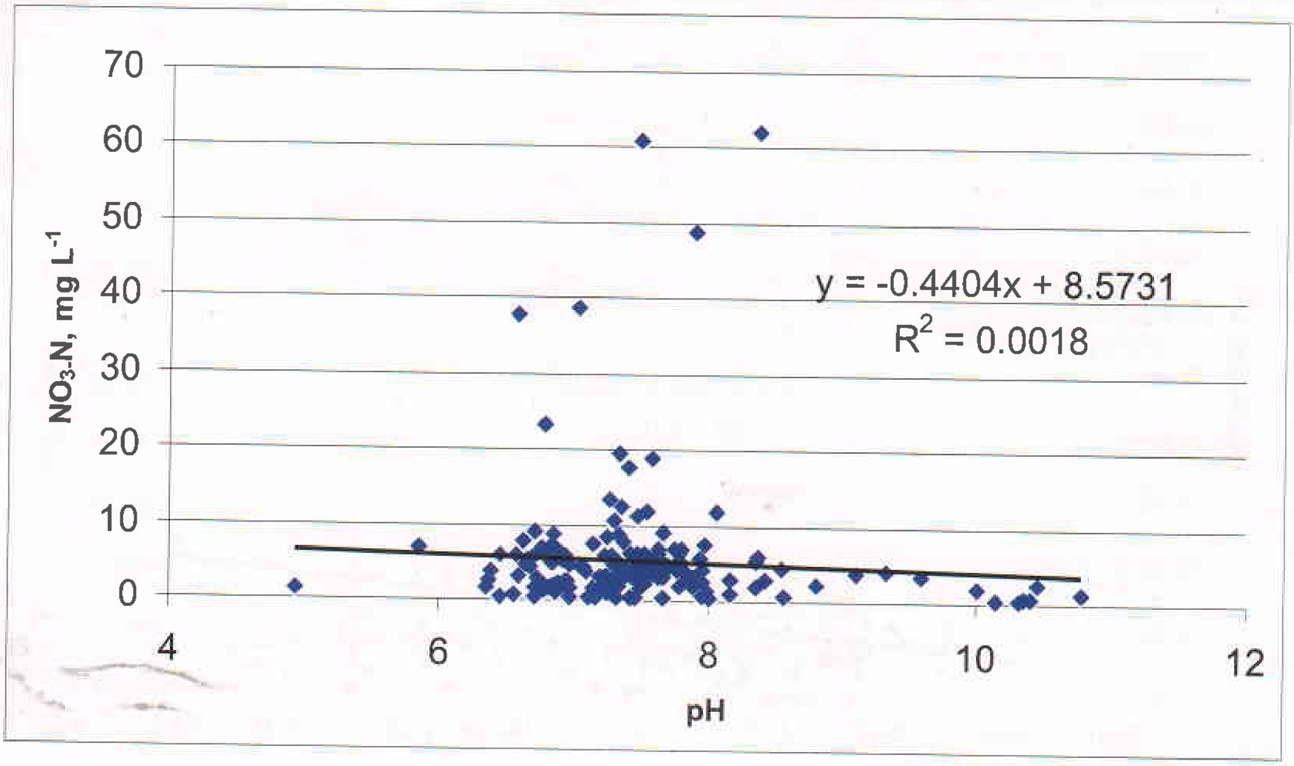


Fig.6.49: Relation between soil pH and nitrate in ground water

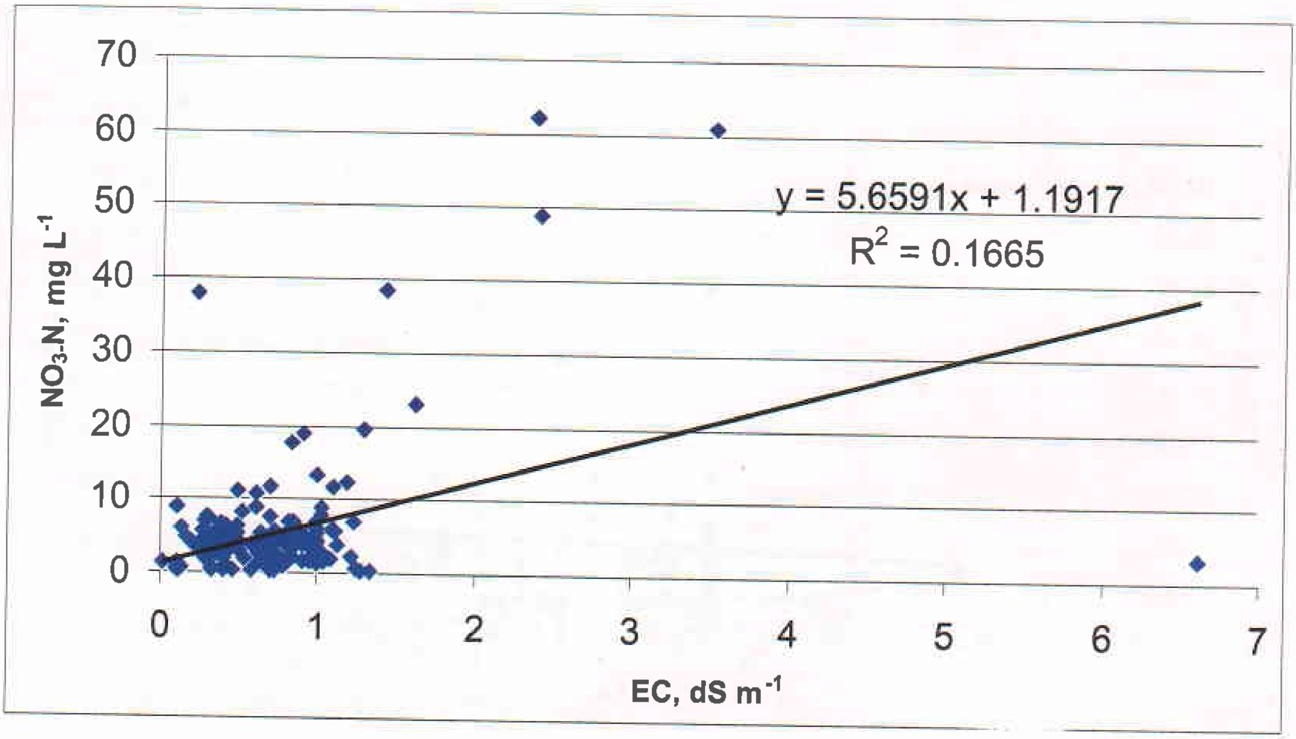


Fig.6.50: Relation between soil EC and nitrate in ground water

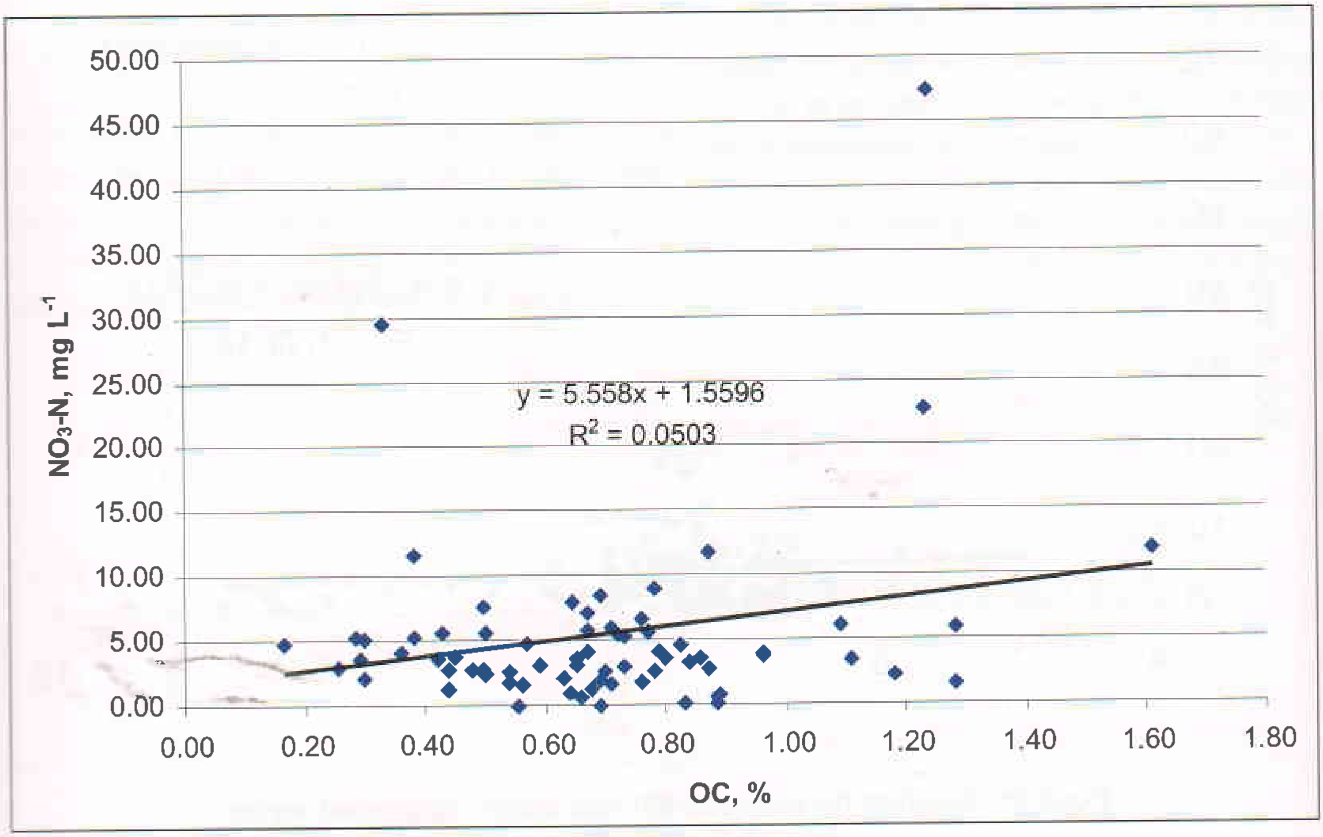


Fig.6.51: Relation between soil OC and nitrate in ground water

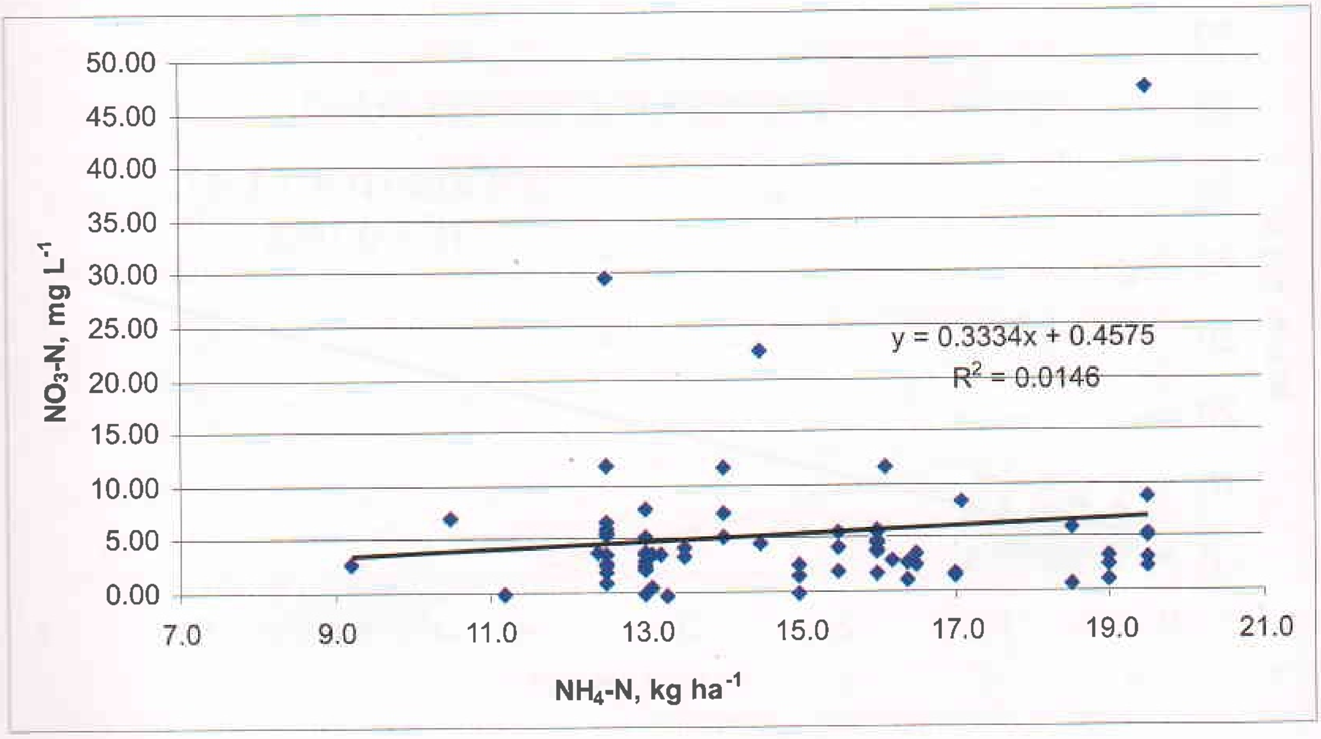


Fig.6.52: Relation between 2M KCl extractable NH_4-N and nitrate in ground water

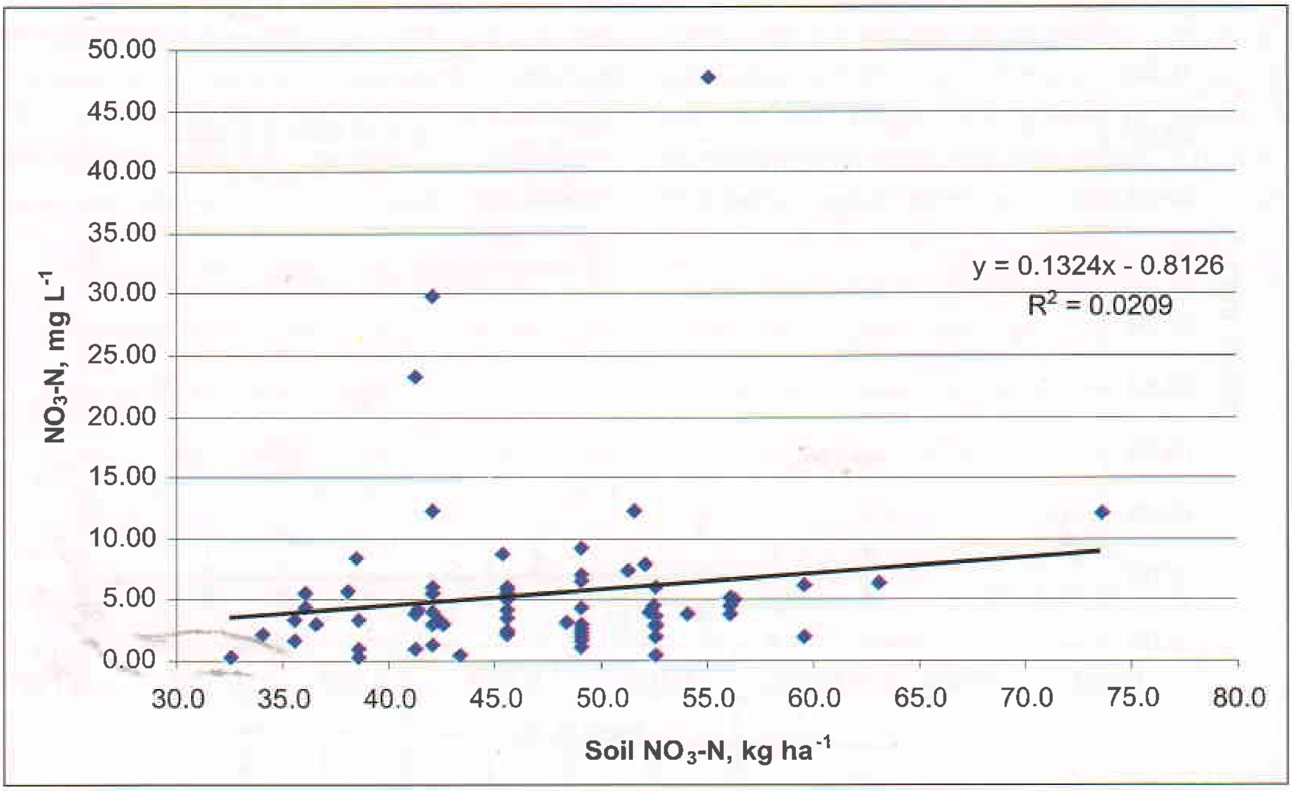


Fig.6.53: Relation between 2M KCl extractable NO_3-N and nitrate in ground water

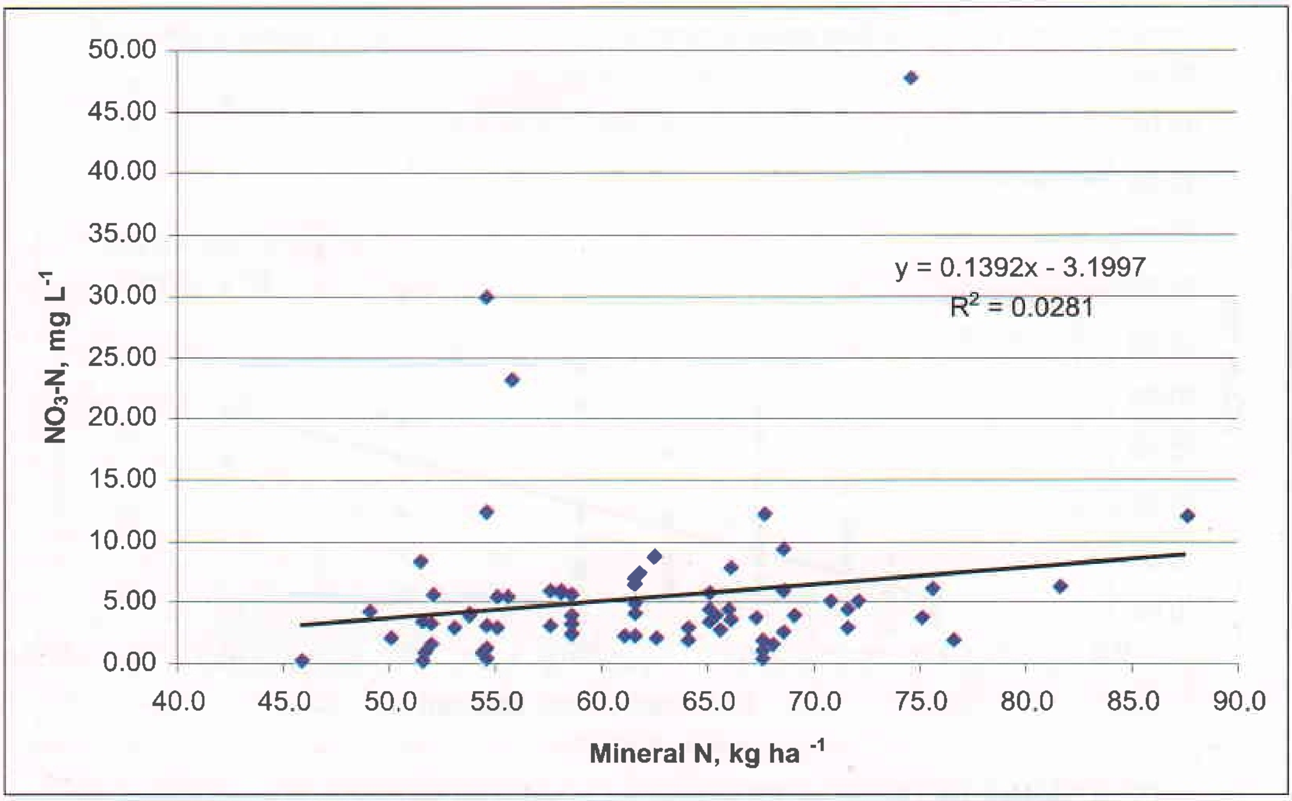


Fig.6.54: Relation between 2M KCl extractable mineral N and nitrate in ground water

Nitrate levels in ground waters had no ificant correlation with any of the water and parameters studied. However, depth of fers, rate of application of organic manures, s/cropping systems seemed to have some ing on the extent and level of nitrate contamination. Most of the hand pumps and open wells, which were incidentally confined to habitation areas, were having lower depth of aquifers and mostly unconfined in nature, and recorded higher level of nitrate pollution (Fig.6.58) Similarly, some land use systems/ cropping

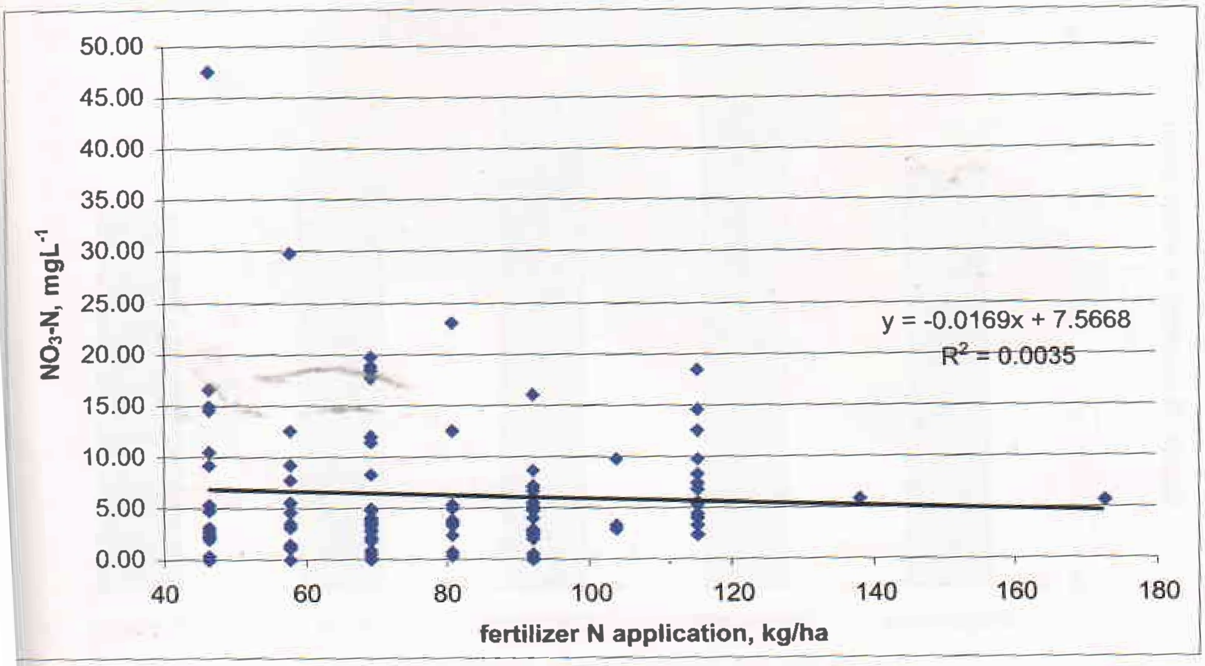


Fig.6.57: Relation between fertilizer application to crops and nitrate in ground water

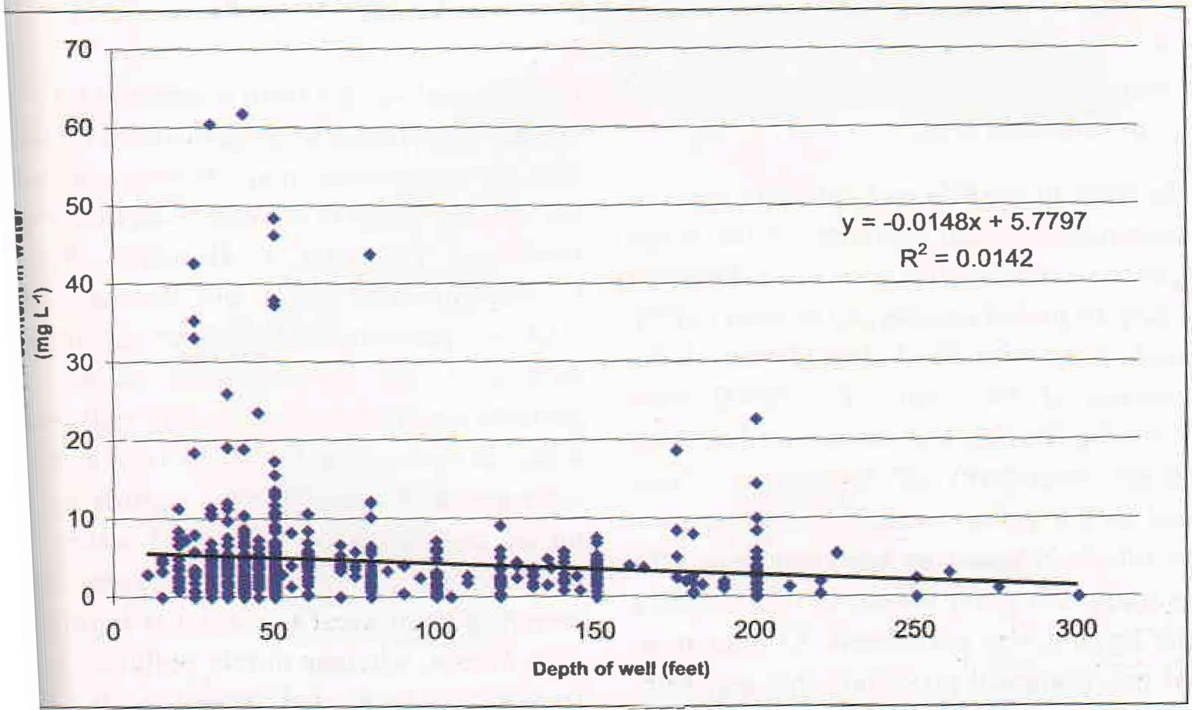


Fig.6.58: Relation between depth of aquifer and nitrate in ground water

systems like orchards and vegetables recorded higher level of nitrate contamination in ground waters as compared to soybean or rice based systems (Fig. 6.59).

Application of organic manures, which were mostly confined to vegetable crops and orchards, resulted in higher level of nitrate in soils and in open wells in its vicinity. Also a very high and significant correlation was obtained between organic manure application and nitrate content in ground waters (Fig. 6.56).

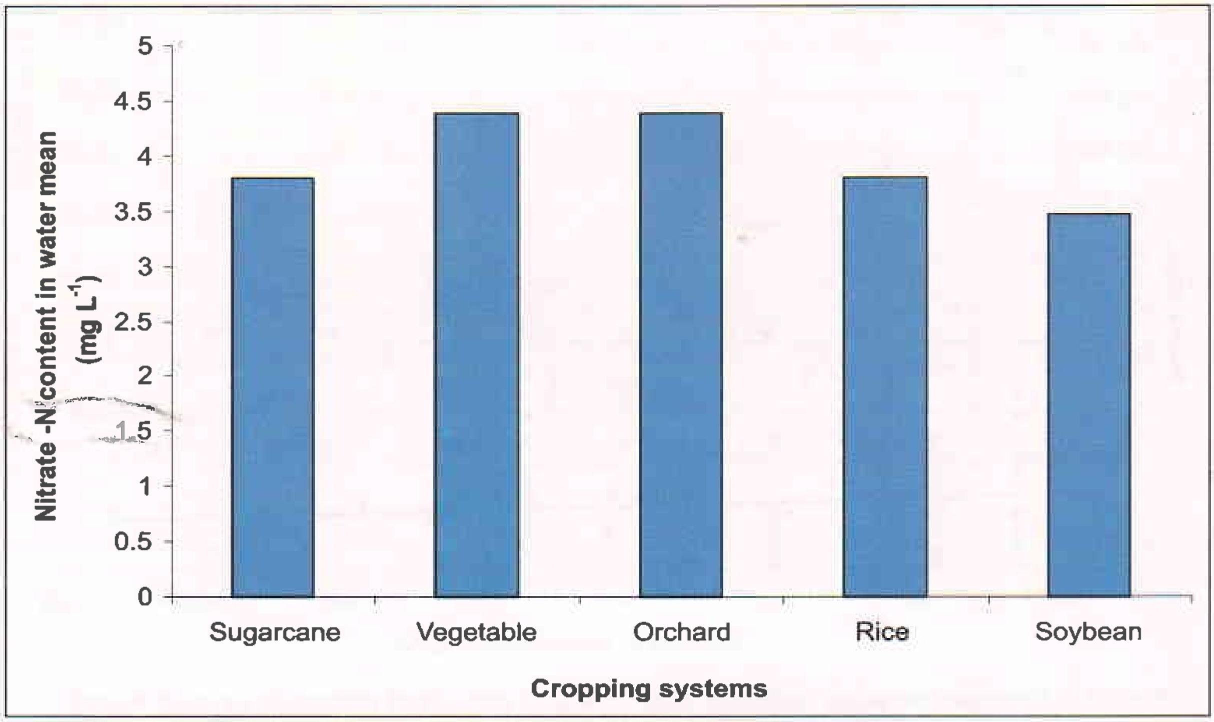


Fig.6.59: Mean nitrate-N content in ground water under different land use systems

6.5 Mapping and delineation of nitrate contaminated areas

In order to identify and delineate areas of nitrate contamination and pollution in the target districts, all the sampling sites were geo-referenced with the help of global positioning system (GPS). The digital maps with block boundaries of the target districts at the scale of 1:50000 were prepared by digitization and mosaicing (merging of digitized boundary) of toposheets. Geo-referenced sample points were assigned the point values of nitrate-N based on laboratory analysis. After assigning the point values to the sampling points the kriging was performed. Kriging is an advanced geo-statistical procedure that generates an estimated surface from a scattered set of points. Gaussian method of kriging was used for the nitrate data-set to generate map. Nitrate contamination maps of the districts of West Godavari (Fig. 6.60), Ferozepur (Fig. 6.61), Hooghly (Fig. 6.62), Coimbatore (Fig. 6.63) and Hoshangabad (Fig, 6.64) are presented below. Each district has been delineated into three distinct classes, namely, polluted areas (as represented by red), vulnerable areas (as represented by yellow) and safe areas (as represented by green) with regards to level of nitrate contamination of ground waters. A close scrutiny of the maps clearly suggests that south-eastern part of West Godavari is highly polluted with nitrate, whereas nitrate pollution is more or less evenly distributed throughout the district of

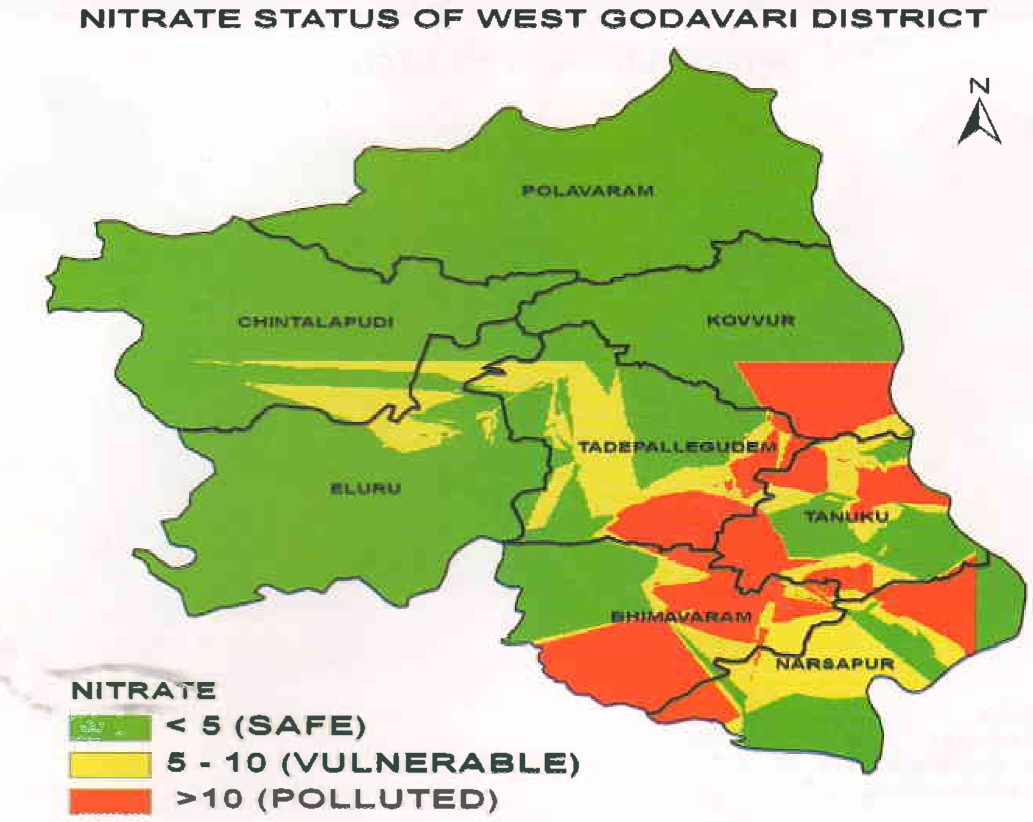


Fig. 6.60: Delineation of nitrate contaminated areas in West Godavari district

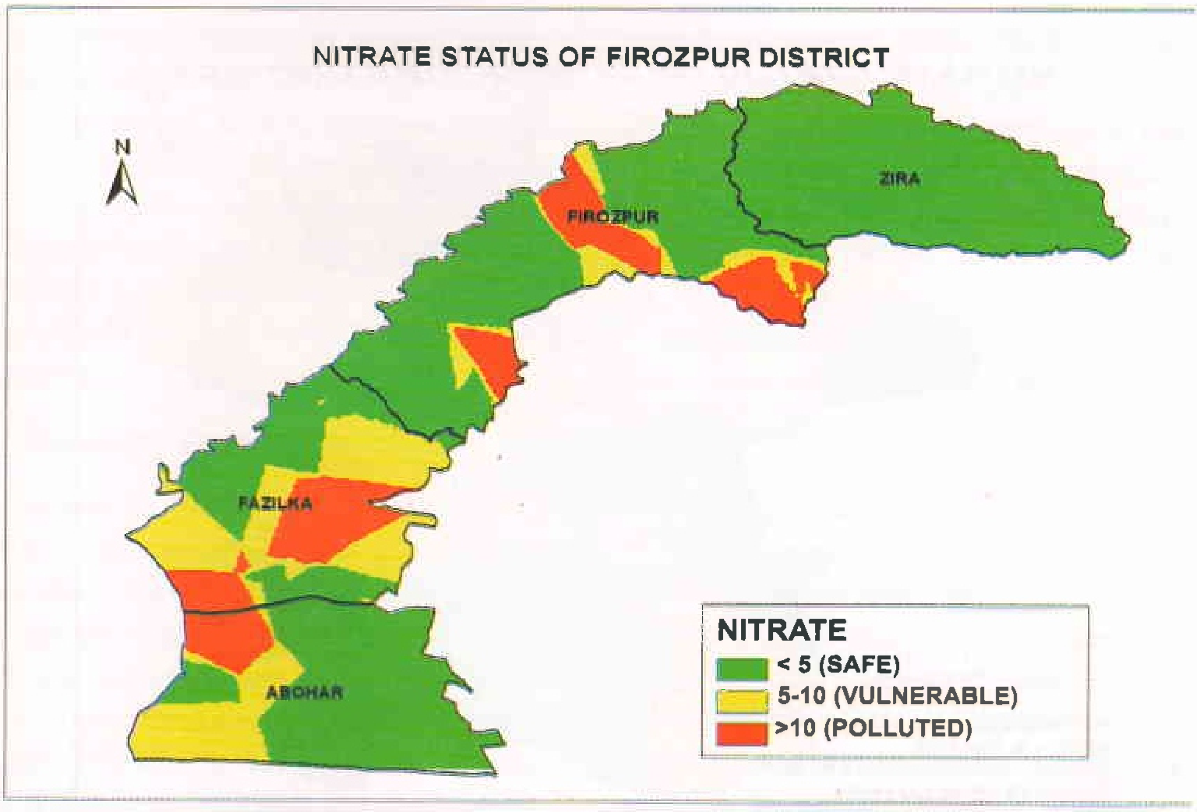


Fig. 6.61: Delineation of nitrate contaminated areas in Ferozepur district

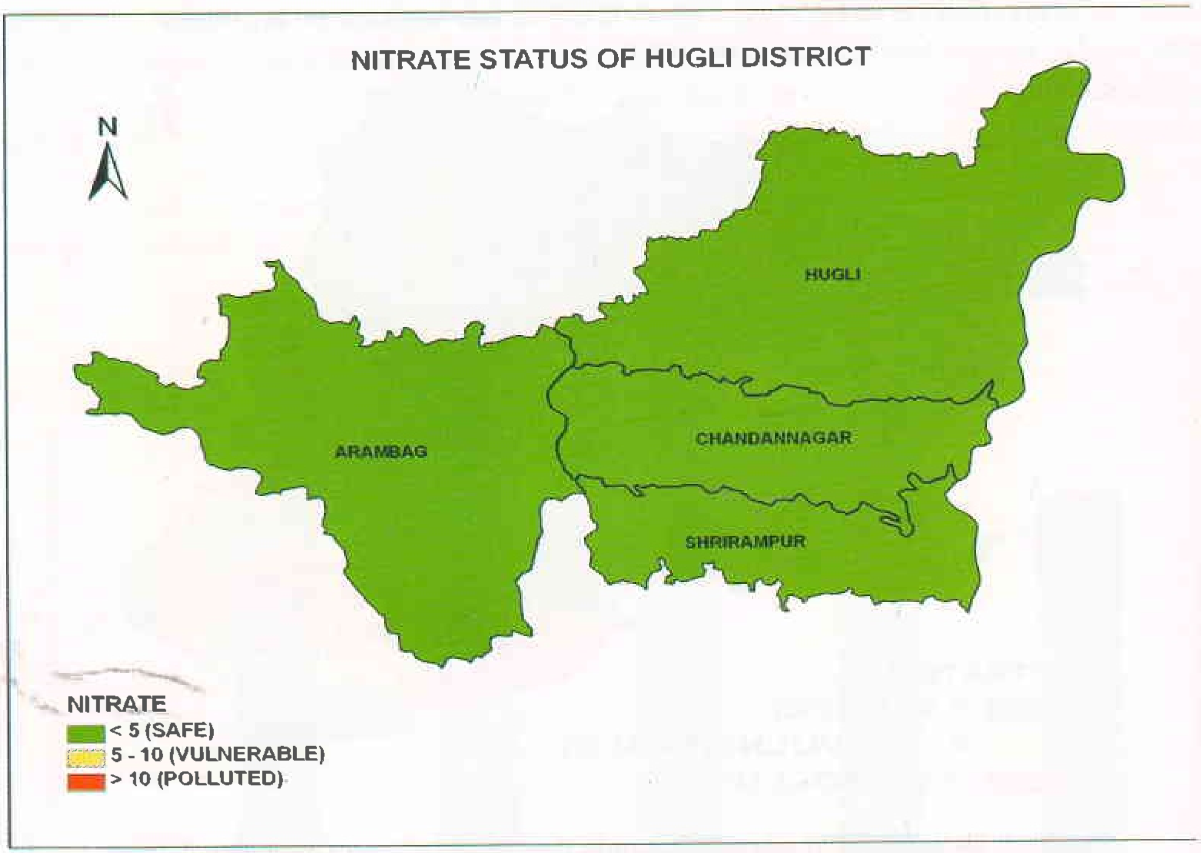


Fig. 6.62: Delineation of nitrate contaminated areas in Hooghly district

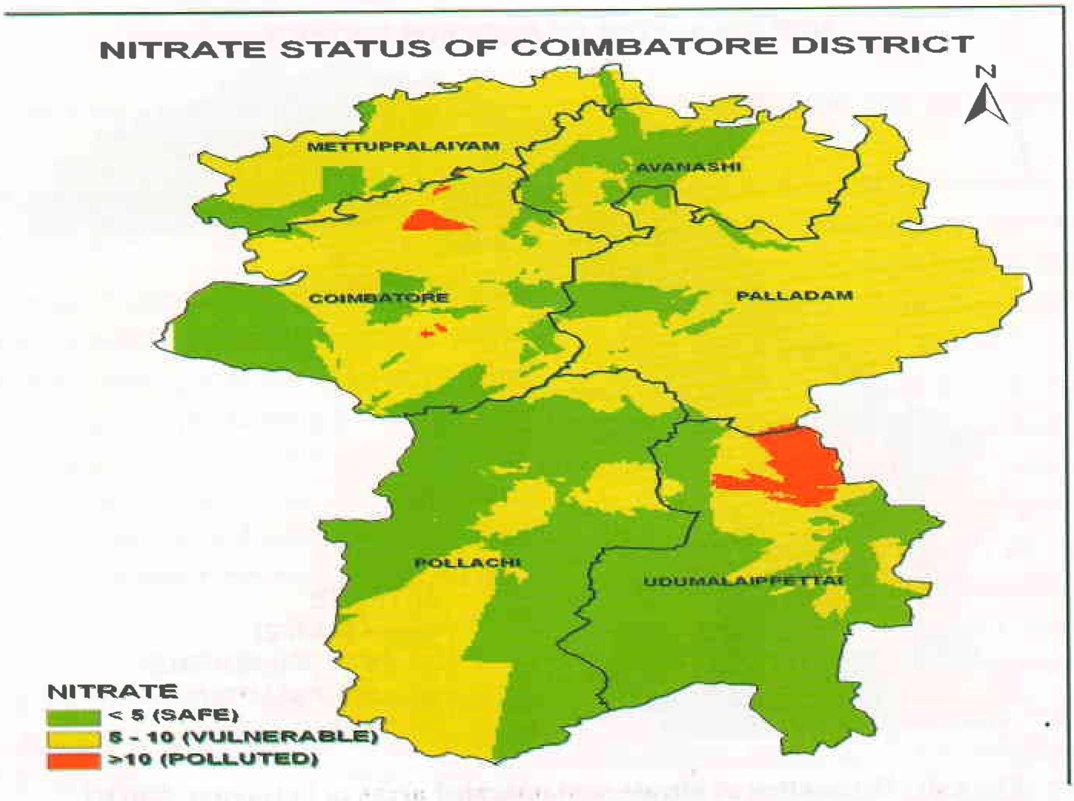


Fig. 6.63: Delineation of nitrate contaminated areas in Coimbatore district

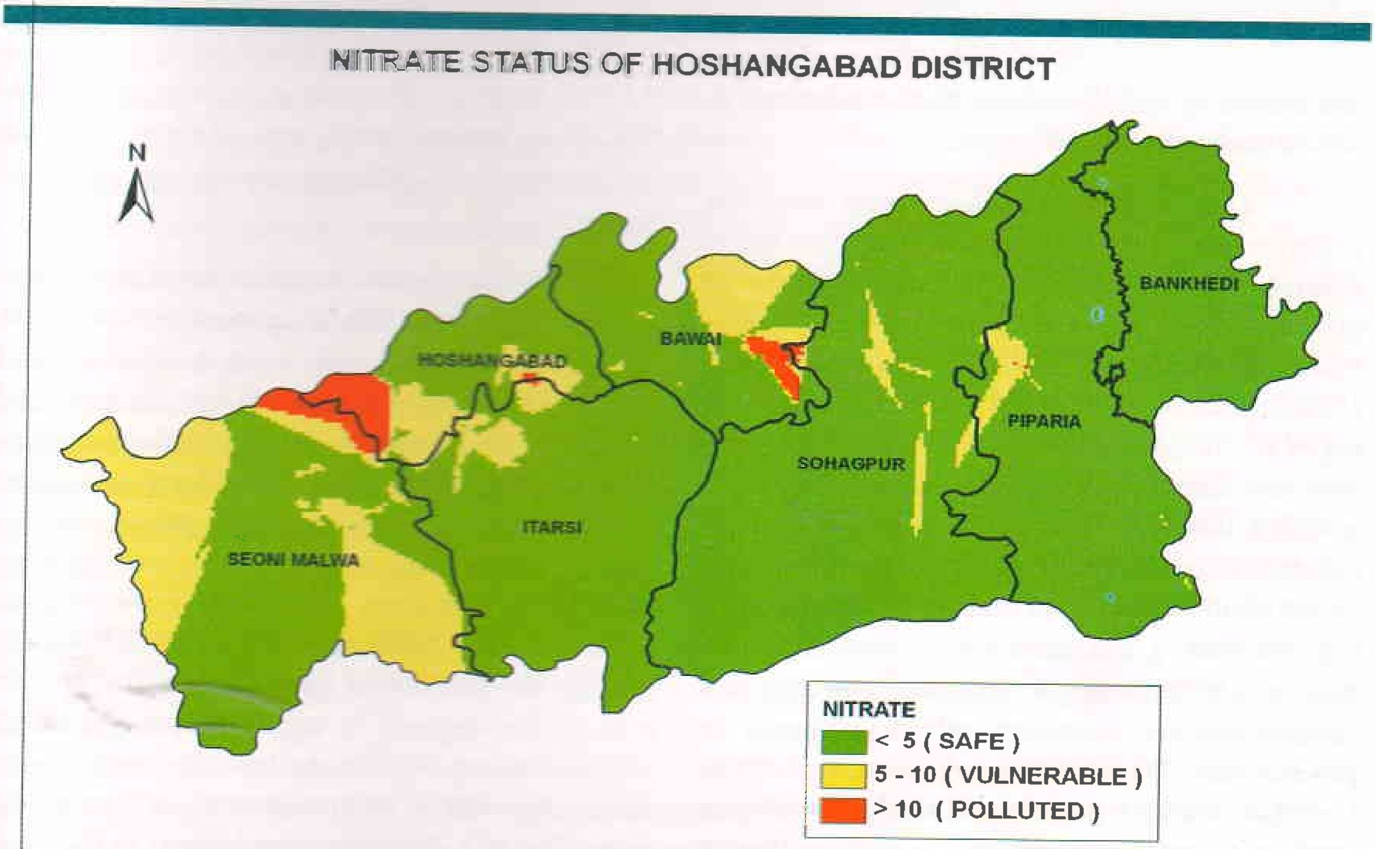


Fig. 6.64: Delineation of nitrate contaminated areas in Hoshangabad district

Ferozepur. Nitrate contents in ground waters of Hooghly are within safe limit, while the ground water resources of almost entire Coimbatore district is vulnerable to nitrate pollution. Nitrate pollution of ground waters of Hoshangabad district is mostly confined in the blocks of Seoni-malwa, Hoshangabad and Babai, and these areas are in close proximity to river Narmada having a very high water table.

7. Summary and Conclusions

Nitrate is one of the major agriculture-derived pollutants leaching to groundwater. Nitrate leaching from agricultural production system is blamed for the rising concentrations of nitrate in ground- and surface waters around the world. In India, there have been sporadic reports of elevated nitrate concentration in groundwater in different parts of the country, and fertilizer has been made the culprit by various environmentalists and green groups without any proper backup of database on nitrate contamination of groundwater. With this premise the project was undertaken to evaluate the extent of nitrate contamination in ground waters in some heavy to moderately fertilized and intensively cultivated districts of the country, and to delineate the factors which impart vulnerability to nitrate contamination of wells/aquifers. Samples were collected by stratified random sampling in a manner so as to collect more samples from high fertilized areas and relatively less samples from low fertilized areas and to collect samples from different sources in proximity to or under the influence of various anthropogenic activities to ascertain the vulnerability of wells to nitrate contamination. Temporal variation in nitrate contamination of selected aquifers was also studied by revisiting the wells with the help of GPS at different seasons of the same year. Relevant soil properties and water parameters were also determined to find the role of these parameters in nitrate loading in ground waters.

There were wide and significant variations in the levels of nitrate in ground waters in the target districts. The mean nitrate-N concentrations of ground waters from the target districts of West Godavari, Ferozepur, Hooghly, Coimbatore and Hoshangabad were 9.11, 3.57, 0.76, 6.74 and 4.55 mg N L^{-1}, respectively. Evidently, West Godavari was the most polluted and Jalgaon the least amongst the target districts in regards to nitrate contamination of ground waters. Highest level and extent of nitrate pollution in groundwater (*i.e.*, >10 mg NO_3-N L^{-1}) was recorded in West Godavari district, while the target district of Hooghly and Jalgaon did not record any nitrate pollution in groundwater. The other three districts, Ferozepur, Coimbatore and Hoshangabad, recorded moderate level of nitrate pollution in their groundwater resources. About 20 per cent of water samples collected from West Godavari were polluted; the figures were 10, 20 and 8 per cent for Ferozepur, Coimbatore and Hoshangabad, respectively. With the help of geo-referencing and kriging, the digital maps with block boundaries of the target districts have been prepared, and nitrate contaminated areas in each district have been delineated.

When the data were stratified with respect to fertilizer usage, high fertilizer usage areas recorded higher level of nitrate pollution as compared to medium and low areas in the districts of West Godavari, Coimbatore and Hoshangabad. NO_3-N load in groundwater samples increased with increasing rate of fertilizer application, contents of organic C, available nitrogen, NO_3-N and sand content of the soil profiles in the district of West Godavari. Nitrate contents of ground water samples were positively correlated with total N and nitrate-N content of soil in Coimbatore district. However, significant relation was not obtained in the district of Hoshangabad. On the other hand, there was significant positive correlation (r = 0.56**) between the average concentrations of NO_3-N in ground water and average fertilizer consumption in different blocks of Hooghly district.

A significant negative correlation was observed between NO_3-N content in water and depth of sampling aquifers in all the districts, and the same had been reflected through the level and extent of nitrate contamination in various sources of water. The results from West Godavari clearly indicated that open wells and hand pumps were far more polluted than other sources, and samples from habitation areas were more polluted than those from crop fields and other areas. In Hooghly, among the sources of groundwater the NO_3-N content was highest in water from dugged-well followed by tube-well > shallow-tube well > mini-deep tube well > deep-tube well in decreasing order. The NO_3-N content was highest in the hand pump followed by open well and the lowest in bore well. Similarly in Hoshangabad while 9 per cent of open well samples were polluted with nitrate, the figures for hand pump and tube well were 10 and 4 per cent, respectively. As a whole, the sources from habitation areas were much more polluted (17.8%) than those from field (5.5%) and dairy (3.7%) areas in West Godavari and Hoshangabad districts. All sources of water in proximity to habitation areas were significantly more polluted than those in proximity to field and dairy areas.

In West Godavari, NO_3-N load in groundwater samples was higher in areas where shallow rooted crops were grown. The concentration of NO_3 was higher in groundwater in areas where lowland rice (double rice area particularly) was cultivated vis-a-vis sugarcane. Similarly, in Hooghly district, nitrate content in ground water was higher in areas where shallow rather than deep-rooted crops were grown. Rice-potato-vegetables, jute-rice-onion and jute-rice-potato were the rotations under which nitrate contents in ground waters were more than under other crop rotations. In contrast, average NO_3^--N in tube well water samples was lowest in paddy-wheat rotation as compared to other crop rotations in Ferozepur district. In cotton- wheat crop rotation 27.6 per cent water samples were having NO_3^--N >10 mg L^{-1} while this value was 23.5, 14.3 and 10.8 in cotton - wheat- garden, cotton - mixed and rice-wheat, respectively. In Coimbatore and Hoshangabad districts also higher nitrate was recorded in ground water in areas under vegetables and orchards/plantation crops as compared to rice-based/soybean-based cropping systems and other field crops.

Salinity seemed to have affected the nitrate pollution of ground waters in a decisive manner only in the district of Ferozepur. NO_3^- -N content in ground waters was having significant positive relationship with EC, Cl^-, Ca^{++}+Mg^{++}, Na^+ and K^+ during different sampling. Mean NO_3^--N concentration during all the three samplings increased with increasing EC of water samples. Such a strong relationship between nitrate levels and EC in water samples did not exist in any other district. In West Godavari, nitrate level in water was correlated better with EC than with pH. When the data were stratified with regards to level of nitrate, there was by and large an improvement in correlation with EC with increase in level of contamination, but not so with pH of water. In Hoshangabad, on the contrary, nitrate levels in water had correlation neither with pH and EC of water nor with pH, EC and OC of soils. Since a strong correlation was found between nitrate levels in water and salinity, there is a need for delineating the effect of salinity on nitrate contamination in the water samples of Ferozepur district. In all the target districts except Ferozepur, there was an overall increase in nitrate contamination of ground waters in post-monsoon season as compared to pre-monsoon season.

The results thus clearly indicated that in most intensively cultivated and heavily fertilized districts of the country, the danger of nitrate pollution of ground waters has become a reality, although the source of the pollution is a combination of many factors and non-point sources and cannot be pointed to inorganic fertilizers alone. Out of six districts surveyed, only the target district of Godavari presented a case wherein all the soil, water and management factors corroborated significantly to suggest that excessive use of fertilizers might have caused nitrate contamination of ground waters and reached a flash point which requires immediate management interventions. In other districts, nitrate N concentration in the groundwater varied widely from place to place though relatively uniform field managements were practiced in the study area. Spatial variation could not be explained by the site specific data, which suggested that an unidentified mechanism might have played an important role. However, shallow and unconfined or semi-confined aquifers like dugged wells, open wells and hand pumps were much more polluted than deep and confined aquifers in all the districts, and organic sources of nutrients including wash-off of agricultural residues, human and animal excreta especially near habitation areas rather than inorganic sources seem to have played the major role in nitrate contamination of groundwater.

However, a systematic investigation on the occurrence and behavior of nitrate in different hydro-geological conditions and its seasonal response in well-defined hydrological units needs to be carried out to design an effective mitigation and management strategies.

References

Addiscott, T.M. (1996). Fertilizers and nitrate leaching. In: Hester R.E. and Harrision R.M. (Eds.), Agricultural Chemicals and the Environment. Issues in Environmental Science Technology Vol. 5, pp 1-26.

Agrawal, G.D., Lunkad, S.K. and Malkhed, T. (1999). Diffuse agricultural nitrate pollution of Groundwaters in India. Water Sci. Technol. 29(3): 67-75.

Bajwa, M.S., Singh B. and Singh, P. (1993). Nitrate pollution of groundwater under different systems of land management in the Punjab. In: P. Narain (Ed.) Proceedings of first agricultural science congress. National Academy of Agricultural Sciences, New Delhi, pp 223-230.

Bijay-Singh and Singh, Y. (2004). Balanced fertilization for environmental quality. Fertilizer News, 49: 107-113.

Cameron K.C., Di H.J. and Mclaren R.G. (1997). Is soil an appropriate dumping ground for our wastes Aust. J. Soil Res. 35: 995-1035.

Chandu S.N., Subbarao N.V. and Raviprakash. S. (1995). Suitability of groundwater for domestic and irrigational purposes in some part of Jhansi District, UP. Bhujal News 10: 12-18.

Deshpande, S.M., Kaplay, R.D. and Kulkarni, S. G. (1999). Nitrate contamination in groundwater of Paithan, Aurangadad District. Pollution Research, 18:191-192.

Fertilizer Statistics (2005-06). Fertiliser Association of India, New Delhi.

Fried, J.J.W. (1991) Sources of nitrates in fissure groundwater in the humid tropical zone-the example of Ivory Cost. J. Hydrol. 113: 231-264.

Gulis, G., Czompolyova, M. and Cerhan, J.R. (2002). An ecologic study of nitrate in municipal, drinking water and cancer incidence in Trnava District, Solvakia. Environ. Res. Sec. A 88: 182-187.

Gupta, N. and Chandrasekharan, H. (1999). Status of nitrate contamination in groundwater near Delhi: A case study. Royal Society of Chemistry (Spl. Publ.), 237: 240-249.

Hudak, P.F. (2000). Regional trends in nitrate content of Texas groundwater. J. Hydrol. 228: 37-47.

Knobeloch, L., Krenz., K., Anderson, H. and Hovel, C. (1992). Methemoglobinemia in an infant-Wisconsin. Morbidity Mortality Weekly Report 42(12): 217-219.

Mukherjee, S. and Pandey, D.S. (1994) Nitrate pollution in groundwater at Jaunpur and its environments, Uttar Pradesh. Bhujal News 9: 22-25.

Mutch, J. (1998). The hydrologic cycle and water movement. Nitrate- agricultural sources and fact in the environment- perspectives and direction. In: Procedings of the Workshop. Eastern Canada Soil and Water Concentration Center, pp. 3-7.

Nolan, B.T., Ruddy, B.C., Hitt, K.J. and Helsel, D.R. (1997). Risk of nitrate in groundwaters of the United States-a national persective. Environ. Sci. Technol. 31: 2229-2236.

Prasad R. (1998). Fertilizer urea, food security, health and the environments. Curr. Sci. 75: 667-683.

Rajmohan N, Elango L and Elampooranam T (1997). Seasonal and spatial variation in magnesium and chloride concentration in groundwater of Nagi Quaid E Milleth District in Tamil Nadu. Indian J. Environ. Prot. 17(6): 448-453.

Singh, B. and Sekhon, G.S.(1978). Nitrate pollution of groundwater from use of nitrogen fertilizers-a review. Agric. Environ. 4: 207-225.

Singh, B., Singh, Y. and Sekhon, G.S. (1995). Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countires. J. Contam. Hydrol. 20:167-184.

Spalding R.F. and Exner M.E.(1993). Occurrence of nitrate in groundwater- a review .J. Environ.Qual. 22: 392-402.

Srinivasa Rao, N. (1998). Impact of clayey soils on nitrate pollution in the groundwater of the Lower Vamsadhara River basin, India. Hydrol. Sci. J. 43: 701-714.

Stredel, O., Duynisveld, W.H.M. and Bottcher, J. (1989). Nitrate pollution of groundwater in Western Europe. Agric. Ecosyst. Environ. 26: 189-214.

Tamta, S.R., Kapoor, S.L. and Goverdhanan, T. (1991). Manurial NO_3 pollution of groundwater in the decan trap formation of Godavari basin-Karanataka: a preliminary case study. Bhujal News 6: 29-33.

Zaporozec, Alexander (1994). Concept of groundwater vulnerability. In: Guidebook on mapping Groundwater Vulnerability. J. Vrda and. A. Zaporozec, eds. International Contributions to Hydrogeology. Volume 16. International Association of Hydrogeologists, London, UK. pp 3-8.

* * *